

UTAH GEOLOGICAL AND MINERAL SURVEY

Report of Investigation 218

TECHNICAL REPORTS OF THE  
WASATCH FRONT COUNTY GEOLOGISTS  
JUNE 1985 to JUNE 1988

Compiled by  
Bill D. Black and Gary E. Christenson

November, 1988

CONTENTS

Preface..... i

Davis County..... 1

D-1 Ward Road landslide..... 2

D-2 Geologic hazards investigation for a proposed water tank site,  
North Salt Lake City..... 3

D-3 Gentile Street landslide..... 6

D-4 Country Oaks Drive landslide..... 7

D-5 Geologic hazards investigation for a proposed water tank site in  
SE 1/4 Sec. 12, T. 1 N., R. 1 W., North Salt Lake City, and Addendum  
to 1986 memo concerning North Salt Lake City upper water tank site..... 9

D-6 Kays Creek landslide near intersection of Fairfield Street and  
Church Street, Layton, Utah..... 21

D-7 Preliminary geologic reconnaissance of Davis County property  
located in the W 1/2 SW 1/4, Sec. 12, T. 1 N., R. 1 W., just south  
of the Concrete Products Company gravel pits..... 25

D-8 Addendum to preliminary geologic reconnaissance of Davis County  
property located in the W 1/2 SW 1/4, Sec. 12, T. 1 N., R. 1 W.,  
just south of the Concrete Product Company gravel pits..... 30

D-9 Geology and geologic hazards, North Davis Refuse District  
disposal site area, Davis County, Utah..... 35

D-10 Preliminary geologic hazard investigation for two proposed  
water storage reservoir sites, Clearfield City, Utah..... 68

Weber County..... 75

W-1 Report of geologic reconnaissance: landslide southwest of Gibbons  
and Reed Co. north pond, west of Uintah, Weber County..... 76

W-2 Investigation of landslide at approximately 5931 South Weber  
Drive, Riverdale, Utah..... 80

W-3 Combe Road landslide..... 83

W-4 Causey Estates landslide..... 86

W-5 Proposed water tank site, NE 1/4, SE 1/4, SW 1/4 Sec. 22, T. 7 N.,  
R. 1 E., just south of the Wolf Creek Development near Eden, Utah..... 91

Salt Lake County.....	98
SL-1 Geoseismic evaluation, Granite fire station, Salt Lake County, Utah.....	99
SL-2 Dresden Lane fault investigation.....	129
Utah County.....	132
U-1 Preliminary geologic hazard investigation for the Emergency Services storage buildings.....	133
U-2 Geologic hazards in the Payson City golf course area.....	138
U-3 A review of geologic hazards for a proposed water tank for Mapleton City, Utah.....	140
U-4 Evaluation of lineaments at the proposed Provo City landfill, Goshen Valley, Utah.....	144

Illustrations

Figure 1. Location map for Weber and Davis counties.....	ii
Figure 2. Location map for Salt Lake, Utah and Juab counties.....	iii

## Preface

The Utah Geological and Mineral Survey (UGMS) acquired funding from the U.S. Geological Survey under the National Earthquake Hazards Reduction Program to place geologists in Wasatch Front County planning departments for a three-year pilot program. Three geologists were placed in five counties beginning in June 1985. Mike V. Lowe worked in Davis and Weber Counties, Craig V. Nelson in Salt Lake County, and Robert M. Robison in Utah and Juab Counties. The UGMS provided technical supervision for the program, but the geologists were staff members of the county planning departments under the supervision of the planning director.

The purpose of the program was to demonstrate to local governments the benefits of having a geologist on staff to aid in land-use planning as it relates principally to geologic hazards. The tasks of the geologists were to: 1) compile geologic hazards information and produce maps to delineate hazard areas, 2) review engineering geology reports, 3) advise planners regarding hazards ordinances, and 4) provide geologic expertise as required, including performing engineering geologic site investigations for critical public facilities and investigating hazard events. Under task 4, technical reports were written to document investigations, and reports completed during the grant period (June 1985 to June 1988) are compiled in this Report of Investigation. They are grouped by county, and locations are shown in figures 1 and 2. The reports were edited by UGMS for content and clarity, but the graphics have not been upgraded and are presented here in their original form or in a reduced form to meet space constraints.

Gary E. Christenson

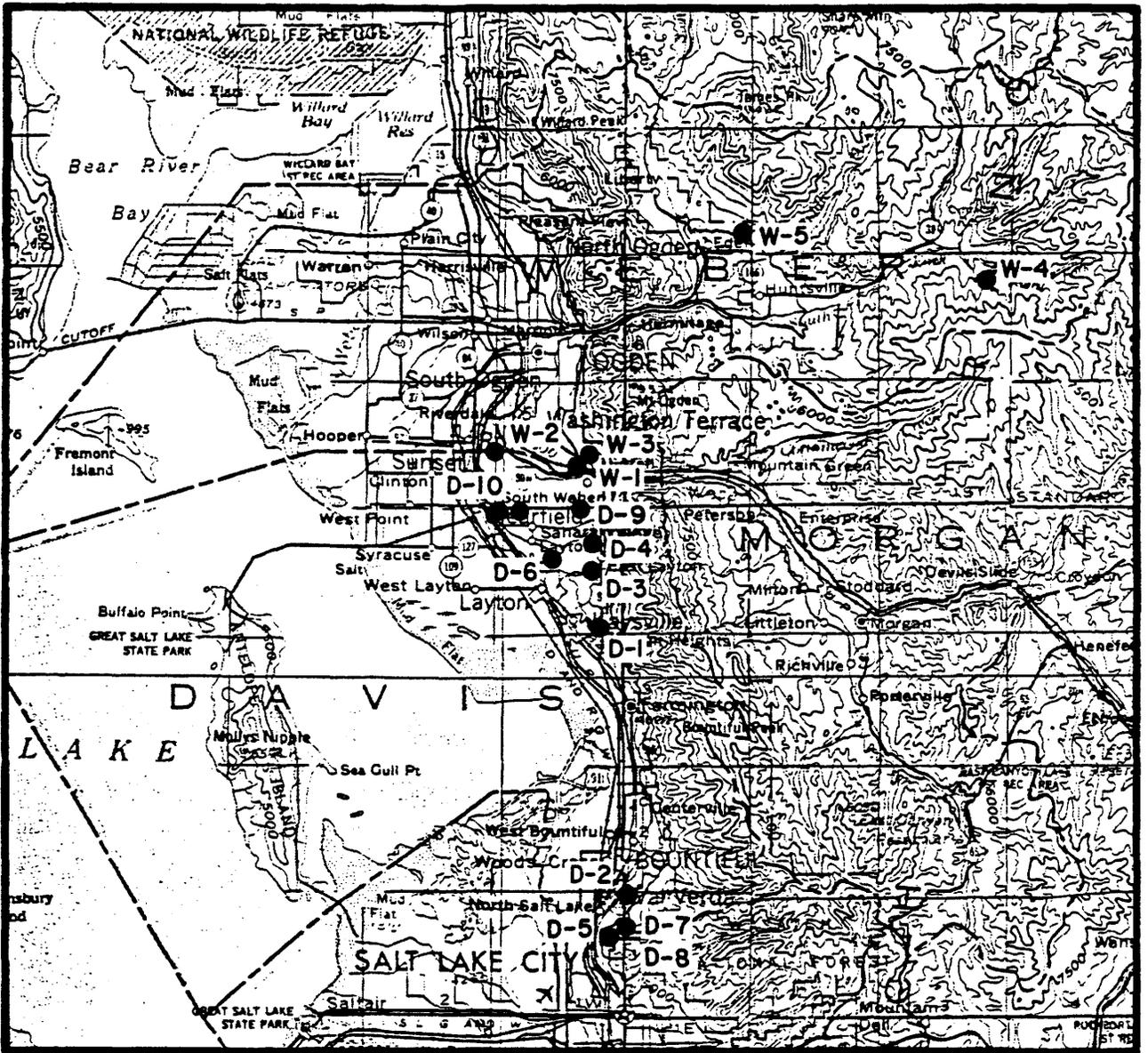


Figure 1. Location map for Weber and Davis Counties.

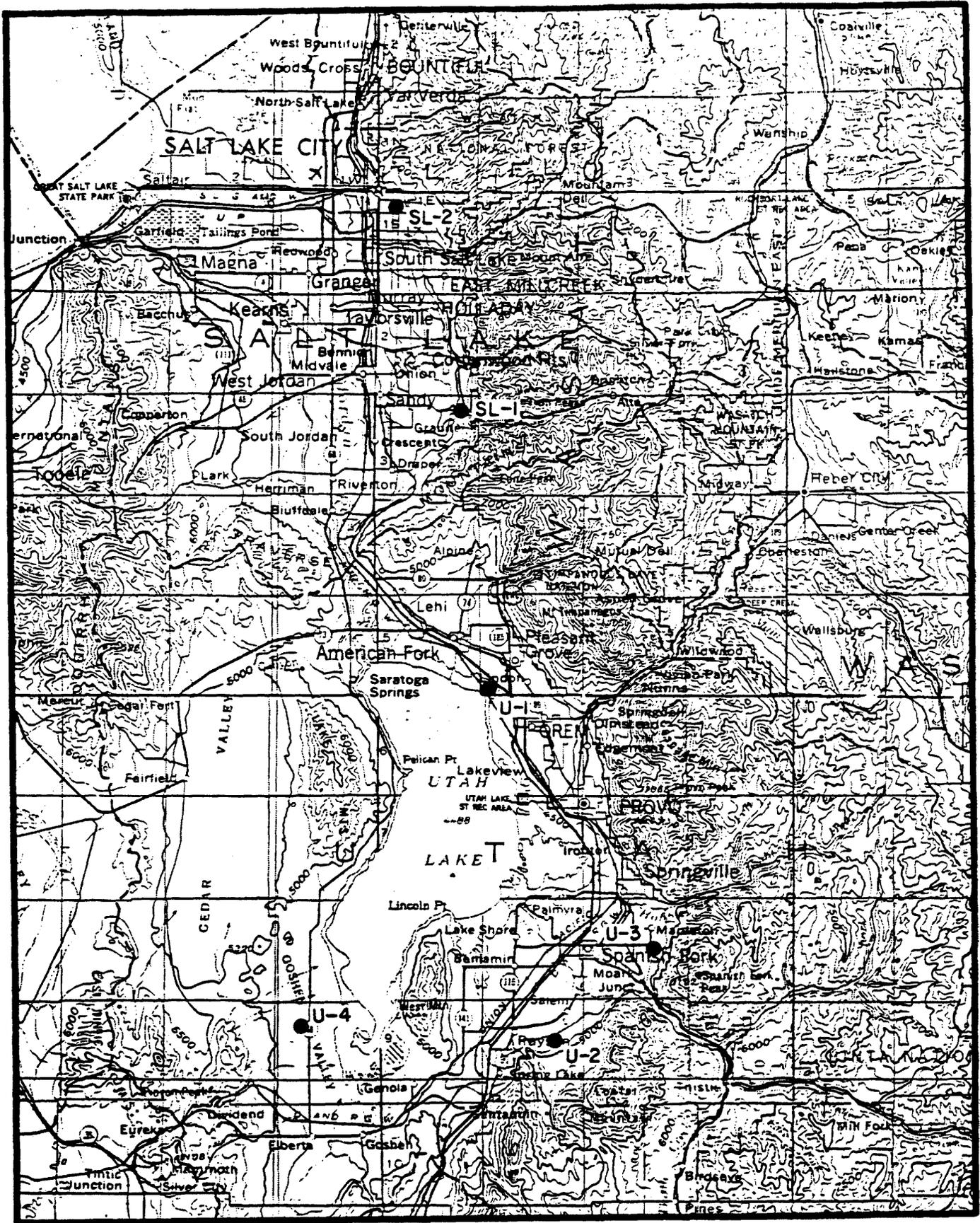


Figure 2. Location map for Salt Lake, Utah, and Juab Counties.

DAVIS COUNTY

Project: Ward Road landslide		Requesting Agency: Davis County Flood Control	
By: Mike Lowe	Date: 3-3-86	County: Davis	Job No.: DI
USGS Quadrangle: Kaysville			

At the request of Sid Smith, Director of Davis County Flood Control, a one-hour field inspection of a landslide located in the NE 1/4 NE 1/4 NE 1/4 sec. 35, T. 4 N., R. 1 W. on the south side of an unnamed drainage just north of Ward Road was made on February 25, 1986. The purpose of this field inspection was to examine an active landslide which had been reported to Davis County Flood Control on February 24, 1986, and assess the possibility of continued movement on the landslide. The scope of investigation consisted of a field inspection only.

The material involved in the landsliding consists of horizontal, cyclically bedded silts and clays of lacustrine origin and colluvium formed on these deposits. The horizontally bedded deposits are bottomset beds of the Weber River delta of Pleistocene-age Lake Bonneville. The slope on which the failure occurred is vegetated, but has been oversteepened by stream downcutting and lateral erosion, and by mass wasting. These processes have formed a wide, flat-bottomed, steep-sided drainage. The landslide consists of two separate failures. For your information, a table and diagram illustrating the landslide classification and terminology used in this memo are included (attachment 1). The initial failure was probably an earth slide in colluvium mantling the slope which partially liquefied and flowed into the drainage. Subsequent to this, slumping of an intact block of the bedded lake deposits occurred at the base of the main scarp of the initial failure. The main scarp is nearly vertical and was estimated to be about 40 feet long. The scarps at the flanks are approximately 10 feet high near the head of the landslide. The landslide deposit is estimated to be about 50 feet long from head to toe, 40 feet wide near the head, and up to 4 feet thick.

Because the slope of the main scarp of this landslide is steeper than the surrounding slopes, there is a possibility of further failure at this location. No crown cracks were noted during the field inspection, although cracks were noted along the west flank of the landslide. It is possible that future landsliding may affect the drainage below the slide.

<b>Project:</b> Geologic hazards investigation for a proposed water tank site, North Salt Lake City		<b>Requesting Agency:</b> North Salt Lake City Engineer	
<b>By:</b> Mike Lowe	<b>Date:</b> 3-11-86	<b>County:</b> Davis	<b>Job No.:</b> D2
<b>USGS Quadrangle:</b> Salt Lake City North			

At the request of Fred Campbell, North Salt Lake City Engineer, an investigation of a proposed site for a 1-million gallon concrete water tank was performed. The tank will be about 100 feet in diameter and, if conditions allow, will be completely buried. The site is north of Center Street and west of Davis Boulevard in North Salt Lake City in the SW 1/4 SW 1/4 SE 1/4 sec. 1, T. 1 N., R. 1 W. (attachment 1). The purpose of this investigation was to identify any geologic hazards affecting the site. The scope of work for this investigation included a literature search and a field inspection on February 28, 1986. During the field inspection, three test pits were examined and logged. Gary Christenson (Utah Geological and Mineral Survey) was present during the field inspection.

The site is northwest of the mouth of a unnamed drainage at an approximate elevation of 4530 feet. The site is underlain by a variety of materials, including fill (historic), alluvium (post-Lake Bonneville), and shoreline sands (post-Provo stage of Lake Bonneville, deposited about 14,500 to 13,500 years ago) (Currey and others, 1984). These materials were exposed in the three test pits (attachment 2) which were logged during the field inspection (attachments 3). The type of materials underlying the shoreline sands in the bottom of the test pits is not known, but may include silts and clays deposited by Lake Bonneville when the lake was at it's maximum between about 16,000 and 14,500 years ago (Currey and others, 1984).

The site is at the southern end of the Ogden segment of the Wasatch fault zone. This fault zone is considered capable of generating earthquakes up to magnitude 7.0 - 7.5, with surface fault rupture and severe ground shaking (Schwartz and Coppersmith, 1984). Zones of greatest deformation along normal faults such as the Wasatch fault are found on the downthrown (west) side where ground cracking may occur in a zone several hundred feet wide. In this area a well-defined main fault trace is not present, and the zone consists of several segments in a broad zone. The site is about 900 feet west of possible faults or ruptures as mapped by Cluff and others (1970). It is 200 feet east and 800 feet west of faults mapped by Van Horn (1982) (attachment 4). No surface evidence of faulting is present at or adjacent to the site, although the surface throughout the area has been modified by man. Trenching is not practical because soils are loose and prone to caving in vertical cuts, particularly cuts to a depth required to adequately evaluate offsets in the lake beds underlying alluvial-fan deposits. Deformation related to previous faulting events was not found in the test pits, and these lines of evidence indicate that surface fault rupture has probably not occurred during recent prehistoric earthquakes at the site. The most recent earthquake causing surface faulting along the Ogden segment of the Wasatch fault zone is thought to have occurred within the last 500 years (Schwartz and Coppersmith, 1984).

The site is located northwest of an unnamed drainage. Deposits from this

drainage have formed the alluvial fan at the water tank site (Van Horn, 1982). The site has been mapped as being in an area of minimal flood hazard by the Federal Insurance Administration (1978), but some flooding may occur during cloudburst thunderstorms. Kaliser (1976) has rated the site as having a low runoff potential. This drainage was too small to be rated for debris flow or debris flood potential in the study by Wieczorek and others (1983), but the hazard is low.

The site is bounded by slopes which show no evidence of instability. Materials at the site consist mostly of coarse granular soils which are generally stable, although cut slopes may be subject to caving and raveling. Ground water was not encountered in the test pits to a depth of 10 feet, and soils are well-drained. Should lake bottom silts and clays be encountered during excavation, problems with caving may be increased. Because of the lack of ground water, the site has a very low liquefaction potential (Anderson and others, 1982).

In conclusion, because the site is along the Wasatch fault, the potential for severe ground shaking accompanying earthquakes is high. The site is in Uniform Building Code (UBC) seismic zone 3 and Utah Seismic Safety Advisory Council (USSAC) seismic zone U-4, the zones of highest seismic risk in Utah in the respective zonations. Construction should incorporate earthquake-resistant design required for UBC seismic zone 3, with inspection and monitoring as outlined for USSAC seismic zone U-4. With regard to surface fault rupture hazard, no deformation due to surface faulting was noted in the test pits and no surficial evidence of faulting was observed. To further evaluate the fault rupture hazard, it is recommended that the walls of the open excavation for the tank be inspected by the Davis County Geologist or other qualified engineering geologist for evidence of fault offsets. If none are found or if those found predate the most recent prehistoric earthquakes along the major fault trace as surficial evidence suggests, the hazard is reduced and the site can be considered suitable. If major, recently active faults are found, alternate sites should be considered. However, whether or not evidence for faulting is found, the site is still within the Wasatch fault zone and, in the event of a large earthquake, tank failure due to offset in the foundation is possible.

There is a low flood hazard from the unnamed drainage to the southeast. Debris-flow hazards should be low, and slopes are presently stable. It is recommended that a thorough soil foundation investigation be performed prior to construction to evaluate ground-water conditions and engineering properties of soils at the foundation level, and response of site materials to seismic ground shaking. This report should also include recommendations for maximum cut slopes during excavation and construction.

#### REFERENCES

- Anderson, L. R., Keaton, J. R., Aubry, Kevin, and Ellis, S. J., 1982, Liquefaction potential map for Davis County, Utah: Department of Civil and Environmental Engineering, Utah State University, Logan, Utah, and Dames & Moore Consulting Engineers, Salt Lake City, Utah, 50 p.
- Cluff, L. S., Brogan, G. E., and Glass, C. E., 1970, Wasatch fault, northern portion, earthquake fault investigation and evaluation: unpub. report by Woodward-Clyde and Associates for the Utah Geological and Mineral Survey, 27 p.

- Currey, D. R., Atwood, Genevieve, and Mabey, D. R., 1984, Major levels of the Great Salt Lake and Lake Bonneville: Utah Geological and Mineral Survey Map 73, scale 1:750,000.
- Federal Insurance Administration, (1978), Flood Insurance Rate Map I - 01-04, City of North Salt Lake, Utah: Department of Housing and Urban Development, Washington D. C., 1:12,000 scale.
- Kaliser, B. N., 1976, Surface water runoff characteristics of the terrain, Davis County environmental geology study: Utah Geological and Mineral Survey and Davis County Planning Commission, 1:24,000 scale.
- Schwartz, D. P., and Coppersmith, K. J., 1984, Fault behavior and characteristic earthquakes: examples from the Wasatch and San Andreas fault zones: Journal of Geophysical Research, v. 89, no. B7, p. 5681-5698.
- Van Horn, Richard, 1982, Surficial geologic map of the Salt Lake City North Quadrangle, Davis and Salt Lake Counties, Utah: U.S. Geological Survey Miscellaneous Investigation Series Map I-1404, scale 1:24,000.
- Wieczorek, G. F., Ellen, Steven, Lips, E. W., Cannon, S. H., and Short, D. N., 1983, Potential for debris flows and debris floods along the Wasatch Front between Salt Lake City and Willard, Utah, and measures for their mitigation: U. S. Geological Survey Open-File Report 83-635, 45 p.

Project: Gentile Street Landslide		Requesting Agency: Davis County Flood Control	
By: Mike Lowe	Date: 3-25-86	County: Davis	Job No.: D3
USGS Quadrangle: Kaysville			

At the request of Sid Smith, Director of Davis County Flood Control, field inspections were made of a landslide located in the SW 1/4 SW 1/4 NE 1/4 sec. 23, T. 4 N., R. 1 W. on the south side of the North Fork of Holmes Creek just south of Gentile Street on February 25 and March 1, 3, 13, 14, and 24, 1986. The purpose of these field inspections was to examine an active landslide which had been reported to Davis County Flood Control on February 24, 1986, and assess the possibility of continued movement on the landslide. The scope of investigation consisted of the field inspections only.

The material involved in the landsliding consists of horizontal, cyclically bedded silts and clays of lacustrine origin and colluvium formed on these deposits. The horizontally bedded deposits are beds of the Weber River delta of Pleistocene-age Lake Bonneville. The slope on which the failure occurred is vegetated, but has been oversteepened by stream downcutting and lateral erosion, and by mass wasting. These processes have formed a wide flat-bottomed, steep-sided drainage. For your information, a table and diagram illustrating the landslide classification and terminology used in this memo are included (attachment 1).

The initial failure on February 24 was probably an earthslide in colluvium mantling the slope which partially liquefied and flowed into the drainage. On March 2 another smaller earthslide in colluvium occurred on the west edge of the initial landslide. At this time, small wedge-shaped slumps in the bedded lake deposits also occurred about halfway up the main scarp of the initial landslide. On March 14, lateral shear cracks on the east flank widened from 3 to 6 inches to 3 to 4 feet, but failure of this area has not yet occurred.

Landslide dimensions were estimated on March 13. The main scarp is nearly vertical and is about 90 feet long and about 110 feet high. The scarps at the flanks are approximately 7 feet high near the head of the landslide. The landslide deposit is estimated to be about 80 feet long from head to toe, 90 feet wide near the head and up to 5 feet thick. Water was noted discharging from the lake deposits in the main scarp at about the midpoint. The quantity of water discharging from the main scarp was estimated to be about 5 gallons per minute on February 25, but on March 24 less than 1 gallon per minute was leaving the landslide area.

Because the main scarp is steeper than the surrounding slopes, there is a possibility of further failure at this location. Crown cracks were noted about 8 feet from the edge of the main scarp, and lateral shear cracks were noted along both flanks during the March 13 field inspection. It is possible that future landsliding may affect the drainage below the slide. The February 24 event blocked the drainage temporarily, but it reestablished itself by flowing around the landslide deposit.

Project: Country Oaks Drive Landslide		Requesting Agency: Layton City Engineer	
By: Mike Lowe	Date: 4-2-86	County: Davis	Job No.: D4
USGS Quadrangle: Kaysville			

At the request of Bill Flanders, Layton City Engineer, and John Zippro, Director of Davis County Emergency Services, field inspections were made of a landslide located in the SE 1/4 NE 1/4 NW 1/4 sec. 14, T. 4 N., R. 1 W. on the south side of the Middle Fork of Kays Creek just north of Country Oaks Drive on March 19, 20, 21, 26, and April 11, 1986. Bill Flanders, John Zippro, and Bruce Kaliser, State Hazards Geologist with the Utah Geological and Mineral Survey, were present during the March 21 field inspection. Gary Christenson, Utah Geological and Mineral Survey, was present during the April 11 field inspection. The purpose of these field inspections was to examine an active landslide, which first moved on March 15 and had been reported to Layton City on March 18, 1986, and assess the possibility of continued movement on the landslide. The scope of investigation consisted of the field inspections only.

The material involved in the landsliding consists of horizontal, cyclically bedded clays, silts, and fine sands of lacustrine origin (Feth and others, 1966) and colluvium formed on these deposits. The cyclically bedded units are offshore sediments (Miller, 1980) deposited during high stands of lakes occupying the Salt Lake Valley during the Bonneville Cycle from about 30,000 to 10,000 years ago (Currey and others, 1984). The slope on which the failure occurred is vegetated, but has been oversteepened by stream downcutting and lateral erosion, and by mass wasting. These processes have formed a wide, flat-bottomed, steep-sided drainage. For your information, a table and diagram illustrating the landslide classification and terminology used in this memo are included (attachment 1).

The initial failure on March 15, 1986 was probably an earth slide in colluvium mantling the slope which slid to the bottom of the flat-bottomed drainage leaving most of the trees growing on the landslide mass in an upright position. Subsequent failures have been earth slumps which have partially liquefied forming earth flows at the toe of the landslide. These failures have occurred periodically since March 15 and are still occurring.

Landslide dimensions were estimated on March 21. The main scarp is nearly vertical, is about 80 feet long, and varies in height from 13 to 20 feet. The scarp at the west flank is approximately 11 feet high near the head of the landslide. The landslide deposit is estimated to be about 300 feet long from head to toe, 80 feet wide near the head, 100 feet wide near the toe, and up to 15 feet thick. Water was noted discharging from the lake deposits about 13 feet below the top of the main scarp, and at other levels below this, generating small earthflows onto the head of the landslide. The quantity of water discharging from the main scarp was variable depending on moisture conditions during previous days. Residents reported that flows increased rapidly following precipitation events.

In conclusion, this landslide is presently active. Because steep slopes remain, water is present in the main scarp, and water exiting the main scarp in the head area is infiltrating into the landslide, it is likely that further failures will occur at this location during future wet periods. The main scarp of the landslide is presently retreating southward between two residences, causing damage to the back yards of both residences and a wooden fence separating them. The main scarp is 50 feet from the foundation of the house to the west and 90 feet from the foundation of the house to the east of the landslide. These houses do not appear to be in immediate danger from the landslide. However, it is possible that the houses could be affected in the future by the landslide. A meeting of involved residents was attended on April 11 to discuss mitigation measures, and it was recommended that a consultant be retained to study the landslide and recommend a permanent solution. Until mitigation measures are implemented, residents should continue to monitor the landslide, particularly during and immediately after wet periods.

#### REFERENCES

- Currey, D. R., Atwood, Genevieve, and Mabey, D. R., 1984, Major levels of the Great Salt Lake and Lake Bonneville: Utah Geological and Mineral Survey Map 73, scale 1:750,000.
- Feth, J. H., Barker, D. A., Moore, L. G., Brown, R. J., and Veirs, C. E., 1966, Lake Bonneville: Geology and hydrology of the Weber Delta District, including Ogden, Utah: U.S. Geological Survey Professional Paper 518, 76 p.
- Miller, R. D., 1980, Surficial geologic map along part of the Wasatch Front, Salt Lake Valley, Utah: U.S. Geological Survey Map MF-1198, scale 1:100,000.

<b>Project:</b> Geologic hazards investigation for a proposed water tank site in SE 1/4 Sec. 12, T. 1 N., R. 1 W., North Salt Lake City, <u>and</u> , Addendum to 1986 memo concerning proposed North Salt Lake City upper water tank site.		<b>Requesting Agency:</b> North Salt Lake City Engineer	
<b>By:</b> Mike Lowe	<b>Date:</b> 6-24-86 & 1-14-87	<b>County:</b> Davis	<b>Job No.:</b> D5
<b>USGS Quadrangle:</b> Salt Lake City North			

At the request of Fred Campbell, North Salt Lake City Engineer, an investigation of a proposed site for a 1-million gallon concrete water tank was performed. The tank will be about 106 feet in diameter and, if conditions allow, will be completely buried. The site is about 750 feet south of the south end of Gary Way in the SE 1/4 NE 1/4 SE 1/4 sec. 12, T. 1 N., R. 1 W. (attachment 1). The purpose of this investigation was to identify any geologic hazards affecting the site. The scope of work for this investigation included a literature search and two one-hour field inspections on May 22 and 23, 1986. Fred Campbell, Rod Wood (Public Works Director, North Salt Lake City), and Kay Iverson (ESI Engineering, Inc.) were present during the May 23 field inspection.

The site is located at an elevation of approximately 5140 feet at the head of a small gully (attachment 1). The site is underlain by gravels, sands, and cobbles which were deposited as lakeshore embankments (Van Horn, 1982) when Lake Bonneville stood at its highest level about 16,000 to 14,500 years ago (Currey and others, 1984). To the north of the site in the bottom of the gully, bouldery to clayey silt alluvial-fan deposits which are younger than the Bonneville shoreline have been mapped by Van Horn (1982). No subsurface investigations were conducted at the site and materials encountered at depth during excavation are not known. However, exposures in the gravel pit just to the northeast of the site indicate that the shoreline sands and gravels are quite thick and that the excavation will be entirely in these deposits.

The site is at the southern end of the Ogden segment of the Wasatch fault zone. This fault zone is considered capable of generating earthquakes up to magnitude 7.0 - 7.5, with surface fault rupture and severe ground shaking (Schwartz and Coppersmith, 1984). Zones of greatest deformation along normal faults such as the Wasatch fault are found on the downthrown (west) side where ground cracking may occur in a zone several hundred feet wide. In the site area, a well-defined main fault trace is not present and the zone consists of several segments in a broad zone. Original fault mapping from air photos by Cluff and others (1970) showed vegetation lineaments 600 feet west and 900 feet southeast of the site (attachment 2). Subsequent detailed field mapping by Van Horn (1982) indicates the nearest fault to be 1,100 feet west of the site (attachment 3). No surface evidence is present at or in the immediate vicinity of the site. No evidence of faulting was found in the gravel pit exposures northeast of the site. Trenching is not attempted because of the lack of surface evidence for faulting and because the soils are loose and prone to caving in vertical cuts. The shoreline platform on which the water tank will be placed is relatively flat and should therefore preserve scarps related to previous surface faulting events. The most recent earthquake causing surface faulting along the Ogden segment of the Wasatch fault zone is thought to have occurred within the last 500 years (Schwartz and Coppersmith, 1984). These lines of evidence indicate that surface

fault rupture has probably not occurred during recent prehistoric earthquakes at the site.

The site has been mapped as being in an area of minimal flood hazard by the Federal Insurance Administration (1978). Kaliser (1976) has rated the site as having a low runoff potential. No evidence of debris-flow deposits were noted at the site.

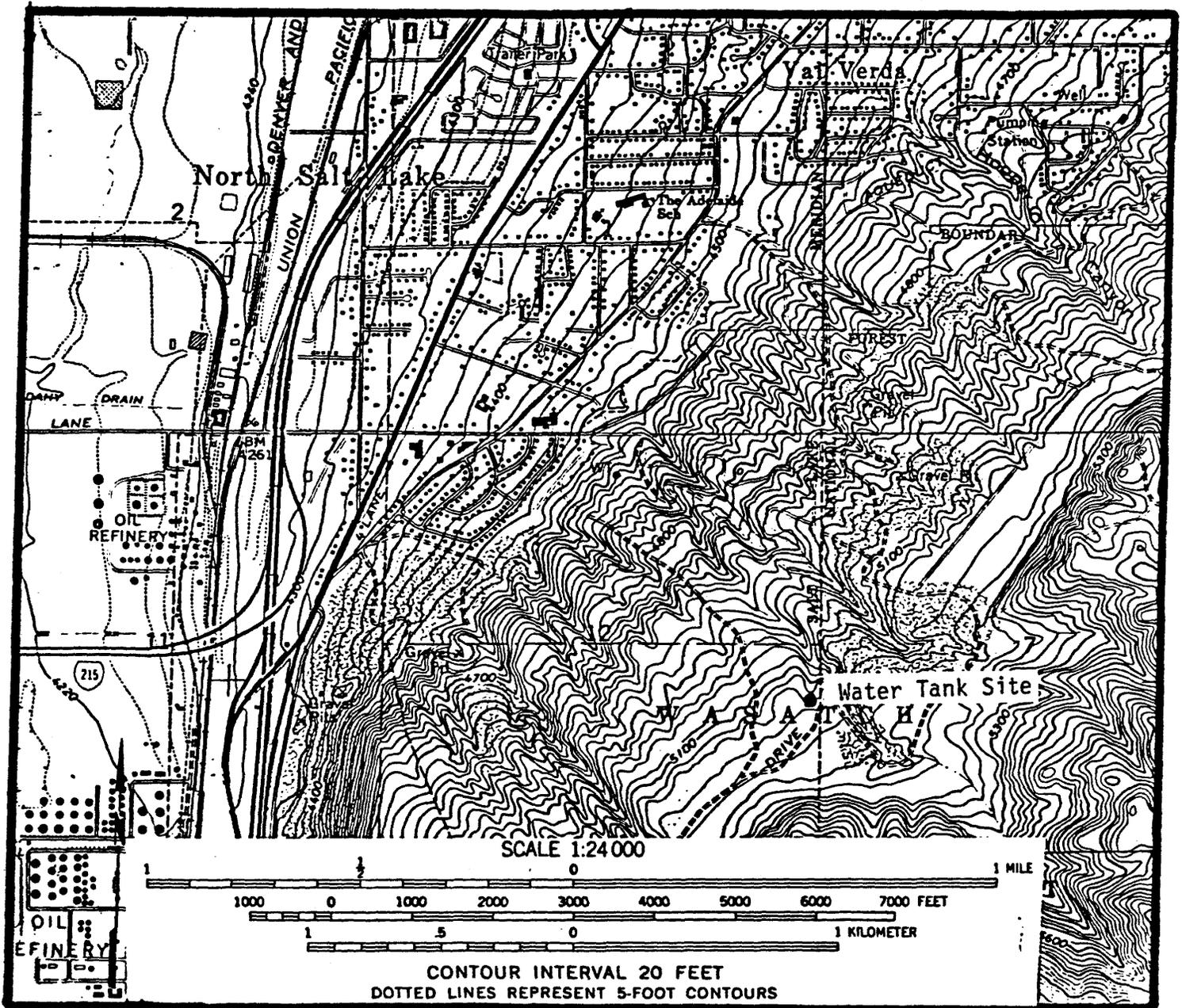
The site is bounded by slopes which show no evidence of instability. Materials at the site consist mostly of coarse granular soils which are generally stable, although cut slopes may be subject to caving and raveling. Gravel is currently being mined northeast of the site. The water tank should not be placed too close to the walls of the gravel pit excavation and measures should be taken to prevent excavation near the foundation of the water tank after it is built. Ground water was noted exiting the slopes of the gravel pit about 20 feet below the natural ground surface near the site. Should perched ground water be encountered during excavation, problems with caving may be increased. Anderson and others (1982) have rated the site as having a very low liquefaction potential.

In conclusion, because the site is along the Wasatch fault, the potential for severe ground shaking accompanying earthquakes is high. The site is in Uniform Building Code (UBC) seismic zone 3 and Utah Seismic Safety Advisory Council (USSAC) seismic zone U-4, the zones of highest seismic risk in Utah in the respective zonations. Construction should incorporate earthquake-resistant design required for UBC seismic zone 3, with inspection and monitoring as outlined for USSAC seismic zone U-4. With regard to surface fault rupture hazard, no evidence of deformation due to surface faulting was noted in the gravel pit exposures and no surficial evidence of faulting was observed. To further evaluate the fault rupture hazard, it is recommended that the walls of the open excavation for the tank be inspected by the Davis County Geologist or other qualified engineering geologist for evidence of fault offsets. If none are found or if those found predate the most recent prehistoric earthquakes along the major fault trace as surficial evidence suggests, the hazard is reduced and the site can be considered suitable. If major, recently active faults are found, alternate sites should be considered. However, whether or not evidence for faulting is found, the site is still within the Wasatch fault zone and, in the event of a large earthquake, tank failure due to offset of the foundation is possible. Also, pipes carrying water from the tank will cross zones of possible surface fault rupture and valves should be installed at the tank to shut off the water should the pipelines become ruptured.

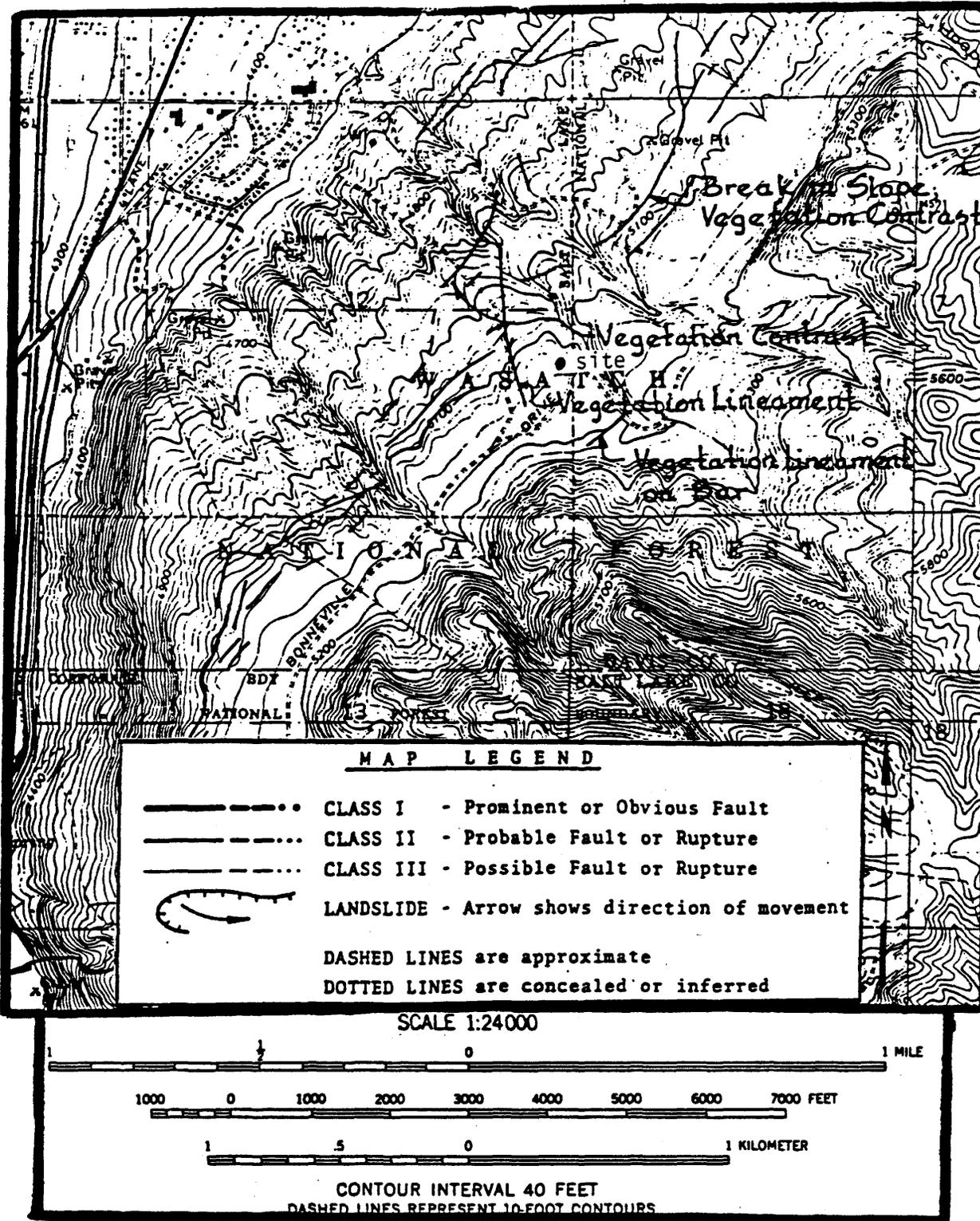
Flood hazard, debris-flow hazard, and liquefaction potential are low. Slopes are presently stable. It is recommended that a thorough soil foundation investigation be performed prior to construction to evaluate ground-water conditions and engineering properties of soils at the foundation level, and response of site materials to seismic ground shaking. This report should also include recommendations for maximum cut slopes during excavation and construction.

## REFERENCES

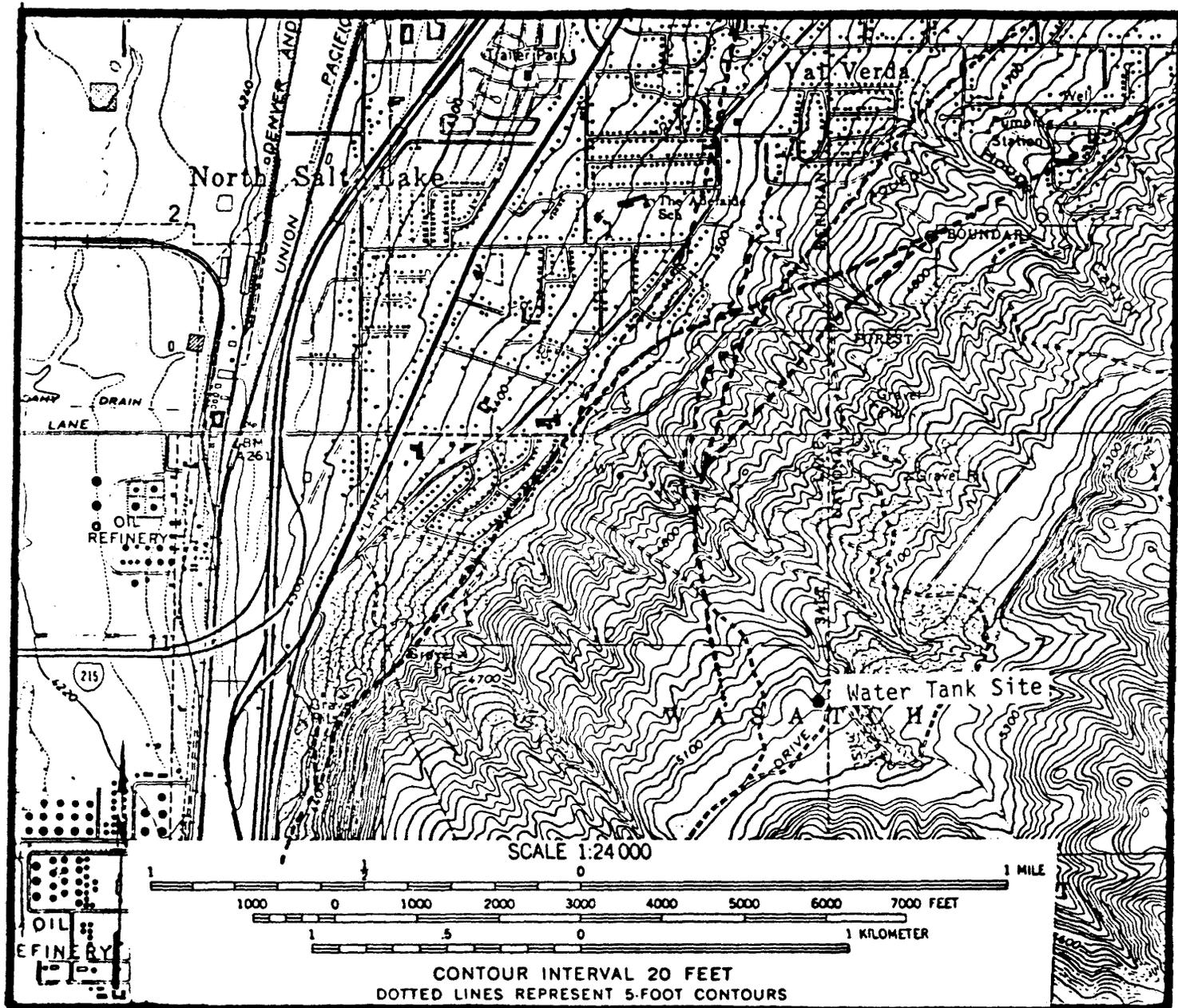
- Anderson, L. R., Keaton, J. R., Aubry, Kevin, and Ellis, S. J., 1982, Liquefaction potential map for Davis County, Utah: Department of Civil and Environmental Engineering, Utah State University, Logan, Utah, and Dames & Moore Consulting Engineers, Salt Lake City, Utah, 50 p.
- Cluff, L. S., Brogan, G. E., and Glass, C. E., 1970, Wasatch fault, northern portion, earthquake fault investigation and evaluation: unpub. report by Woodward-Clyde and Associates for the Utah Geological and Mineral Survey, 27 p.
- Currey, D. R., Atwood, Genevieve, and Mabey, D. R., 1984, Major levels of the Great Salt Lake and Lake Bonneville: Utah Geological and Mineral Survey Map 73, 1:750,000 scale.
- Federal Insurance Administration, 1978, Flood Insurance Rate Map I - 01-04, City of North Salt Lake, Utah: Department of Housing and Urban Development, Washington D. C., 1:12,000 scale.
- Kaliser, B. N., 1976, Surface water runoff characteristics of the terrain, Davis County environmental geology study: Utah Geological and Mineral Survey and Davis County Planning Commission, 1:24,000 scale.
- Schwartz, D. P., and Coppersmith, K. J., 1984, Fault behavior and characteristic earthquakes: examples from the Wasatch and San Andreas fault zones: Journal of Geophysical Research, v. 89, no. B7, p. 5681-5698.
- Van Horn, Richard, 1982, Surficial geologic map of the Salt Lake City North Quadrangle, Davis and Salt Lake Counties, Utah: U. S. Geological Survey Miscellaneous Investigation Series Map I-1404, 1:24,000 scale.



Location Map



Map showing known (Class I) and suspected (Class II, III) traces of surface fault rupture, Wasatch fault zone (from Cluff and others, 1970).



Map showing traces of surface-fault rupture, Wasatch fault zone, Utah (adapted from Van Horn, 1982).

Addendum to 1986 Memorandum Concerning the Proposed North Salt Lake City  
Upper Water Tank Site, January 14, 1987

The purpose of this memorandum is to update the Lowe (1986) memorandum concerning the proposed North Salt Lake City upper water tank site. The previous memorandum concerned the originally proposed site, which has now been moved to a new site approximately 1,000 feet to the south (attachment 1). The scope of investigation included a review of pertinent literature, an examination of aerial photographs (1985, 1:24,000 scale), and a three-hour field investigation of the site which included an examination of three test pits, two of which were logged by Northern Engineering and Testing, Inc. (1986). The principle differences in the sites, which required further evaluation, are anticipated subsurface soil conditions and potential surface fault rupture hazard. Conditions at the new site are similar to the original site in other aspects and recommendations in the Lowe (1986) memorandum still apply.

Surface fault rupture at the new site required investigation because two Utah Division of Water Resources reports (1979, 1986) included a map showing an inferred fault crossing the new water tank site (attachment 2). The faults shown on this map were compiled from several geologic maps which emphasize pre-Quaternary geology. The inferred fault follows the Bonneville Shoreline, and no surficial evidence in Lake Bonneville or younger deposits exists to indicate the presence of a fault. A more recent surficial geologic map by Van Horn (1981), which emphasizes Quaternary geology, does not show a fault at this location (attachment 3). Because of the lack of surficial evidence for faulting at the site, which is on a shoreline platform which would preserve such evidence for faulting in post-Lake Bonneville time, no detailed subsurface investigations were undertaken.

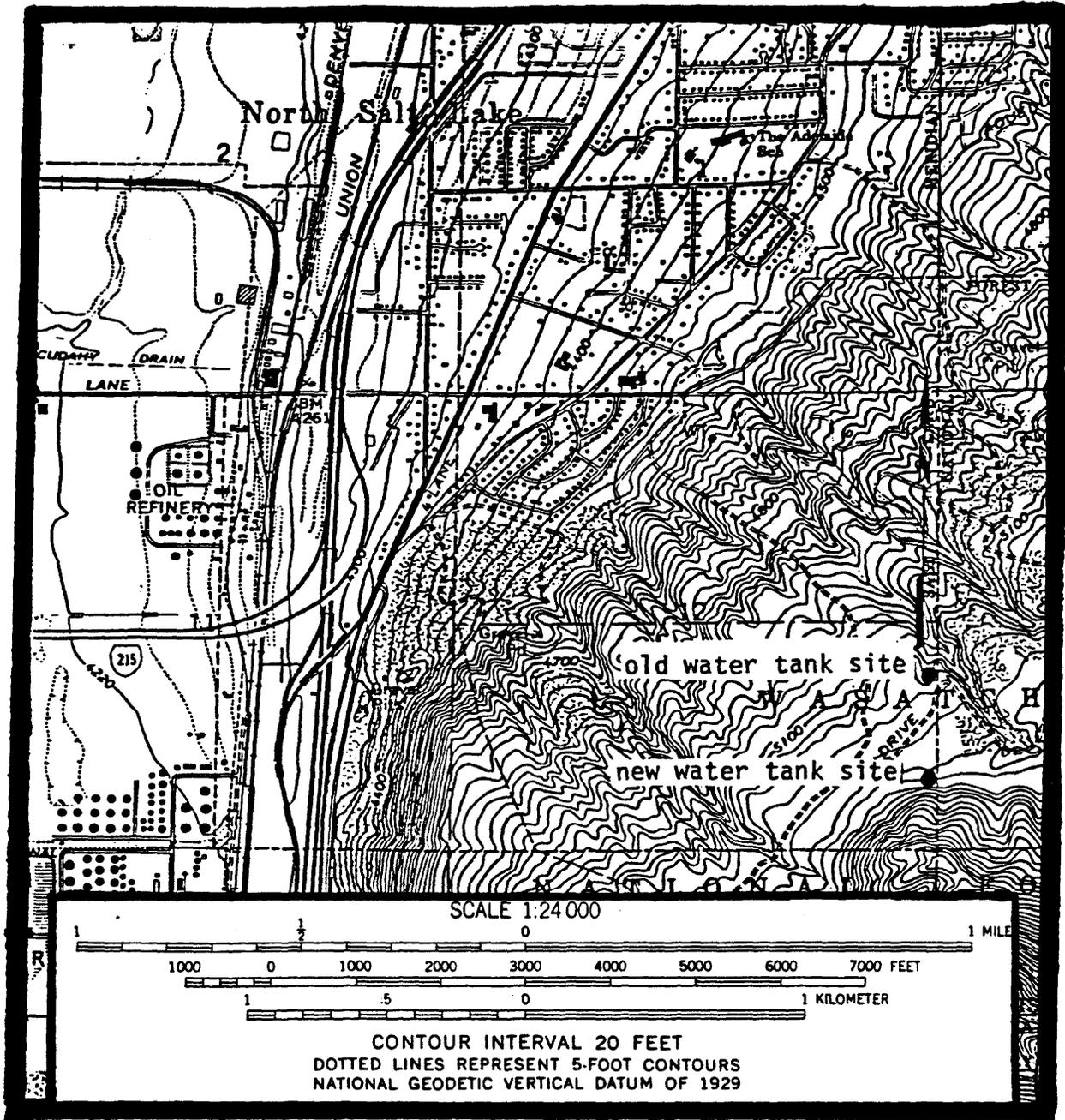
Two test pits (attachment 4) were excavated at the new site as part of a foundation investigation by Northern Engineering and Testing, Inc. (1986), and a third was excavated for this investigation in the vicinity of the suspected fault as mapped by the Utah Division of Water Resources (1979, 1986). Unstratified silty sand deposits containing some matrix-supported gravel-size particles were encountered in all three test pits. In the northern test pit (test pit 2), the silty sand deposits were underlain by a reddish-brown, indurated, clayey sand containing gravel, cobbles, and small boulders. Cobbles were most common at the contact between the two types of deposits (Northern Engineering and Testing, Inc., 1986). The silty sand deposits are most likely slopewash and colluvium derived from the steep slopes immediately south of the site. The lower unit is interpreted to be the Tertiary Wasatch Formation with a thin deposit of Bonneville-age shoreline gravels on it. The site was probably an erosional shoreline platform during Lake Bonneville time. Because of the thickness of the upper slopewash unit in the test pit at the inferred fault (test pit 3, attachment 4), it was not practical to attempt a trench in the area. No evidence of surface faulting was found in the test pits. However, because the test pits did not extend across the entire site, and because they only penetrated the youngest unit for the most part, this is not conclusive evidence to confirm the absence of faulting. Although unlikely, it is possible that evidence for faulting may be found during the excavation for the water tank, and I wish to be notified so that I can inspect the open excavation.

In conclusion, recommendations in the Lowe (1986) memorandum for the previously proposed site also apply to the new water tank site. There is no

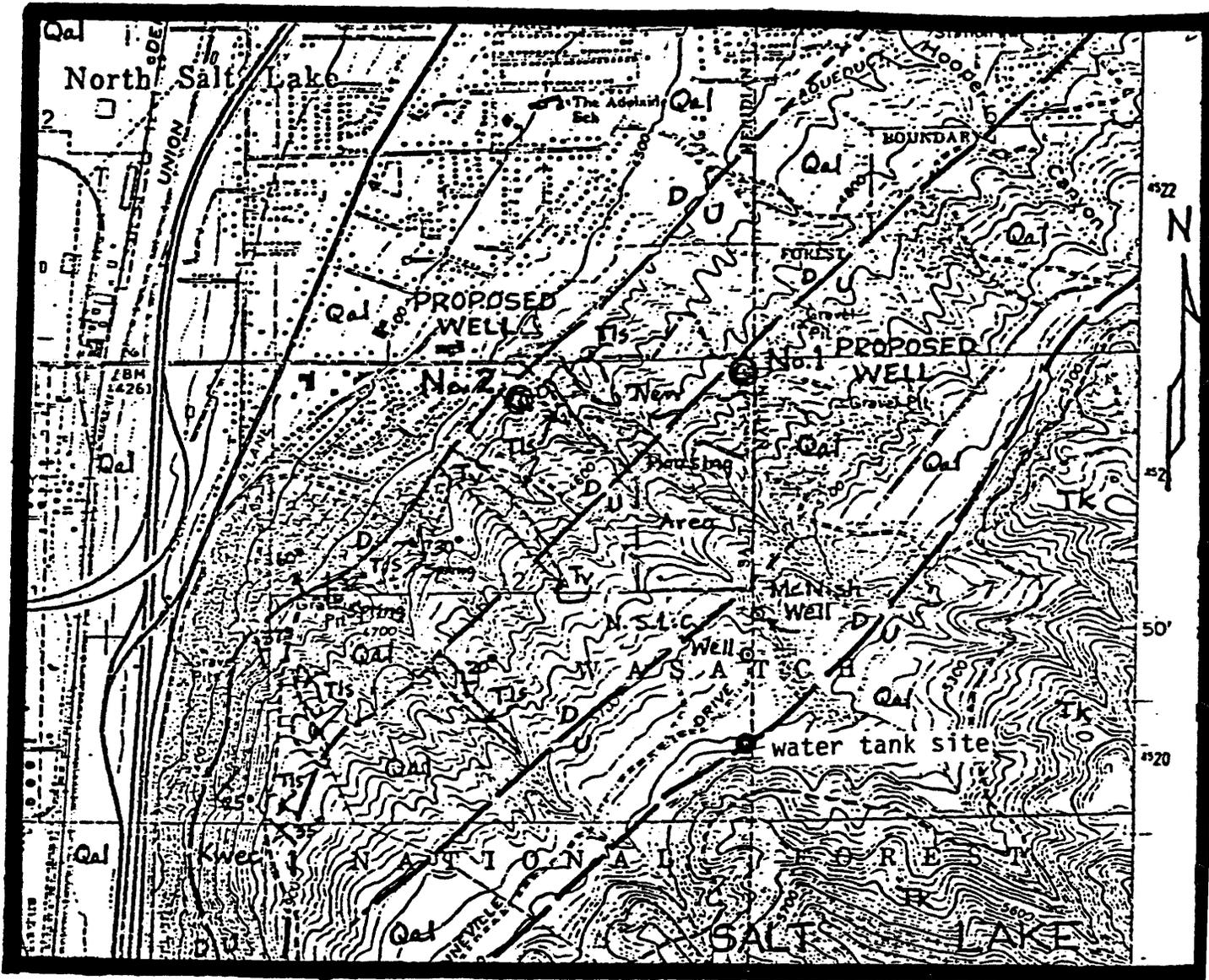
evidence to indicate a surface fault rupture hazard at the site, but I would like to inspect the foundation excavation to confirm this. consolidation tests performed by Northern Engineering and Testing, Inc. (1986) indicate the silty sand deposits may be subject to hydrocompaction. As we discussed on December 23, 1986, these deposits will need to be removed and replaced with compacted fill to prevent possible problems related to differential settlement and/or hydrocompaction. Please notify me when the excavation is open.

#### REFERENCES CITED

- Lowe, Mike, 1986, Geologic hazards investigation for a proposed water tank site in SE 1/4 sec. 12, T. 1 N., R. 1 W., North Salt Lake City: Unpublished Davis County Planning Commission Memorandum, 6 p.
- Everitt, Ben, 1986, North Salt Lake Springs: unpublished Utah Division of Water Resources Memorandum, 4 p.
- Montgomery, S.B., 1979, Well Study for North Salt Lake City: Unpublished Utah Division of Water Resources Memorandum, 5 p.
- Northern Engineering and Testing, Inc., 1986, Report of geotechnical investigation for one million gallon water storage reservoir, North Salt Lake, Utah: Unpublished consultant's report, 4 p.
- Van Horn, Richard, Surficial geologic map of the Salt Lake City North Quadrangle, Davis and Salt Lake Counties, Utah: U.S. Geological Survey Miscellaneous Investigation Series Map I-1404, 1:24,000 scale.



Location Map



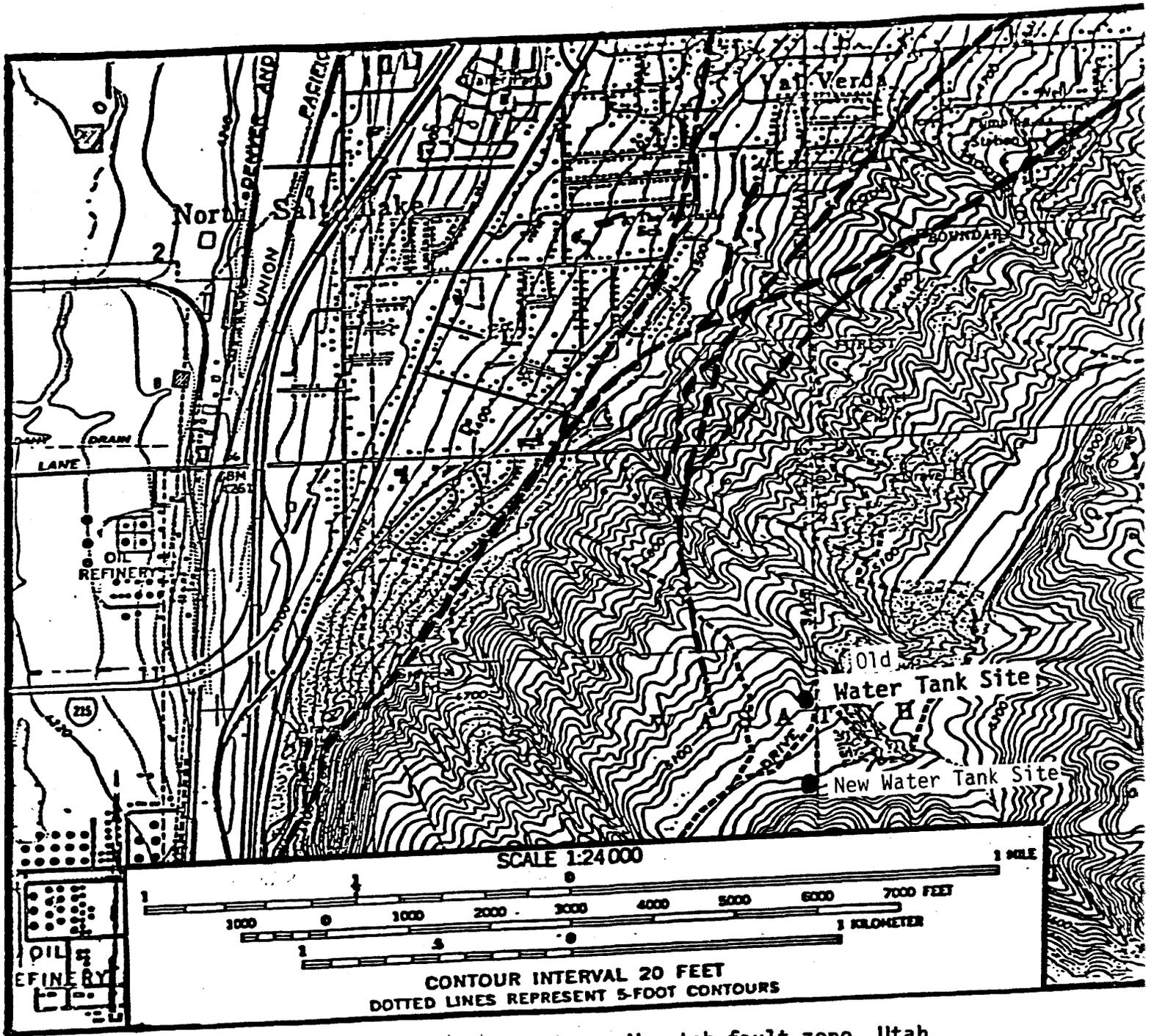
Geologic and well location map  
North Salt Lake City area.  
 1:24,000 scale

Geology modified by Montgomery (1979) from Granger (1952), Marsell (1953), and Crittenden (1964).

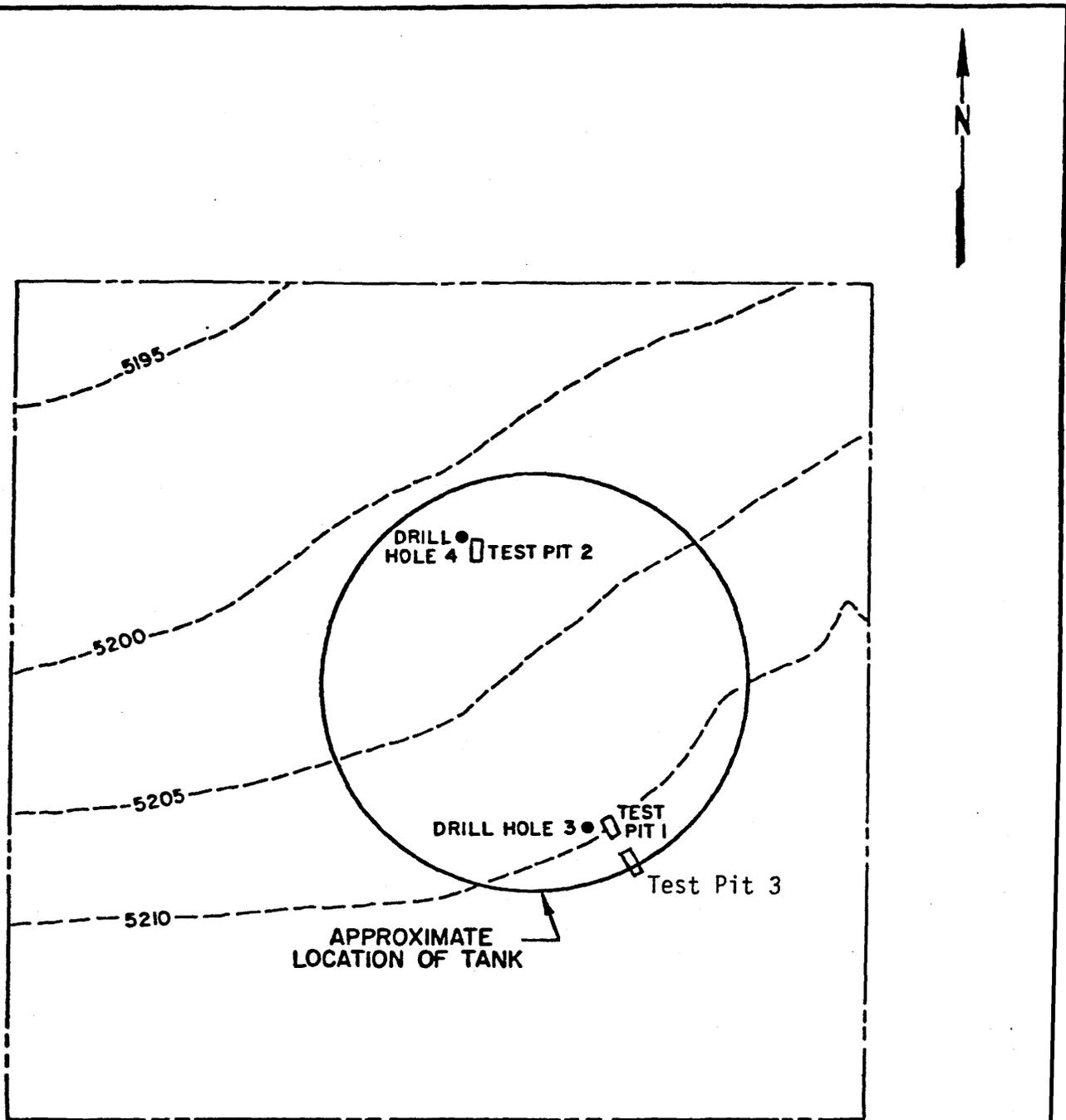
EXPLANATION

Qal = Quaternary alluvium  
 Tv = Tertiary andesite  
 Kwec = Cretaceous Wanship-  
 Echo Canyon Conglomerate  
 --- Formation contact

Tk = Tertiary Knight Conglomerate  
 Tls = Tertiary "limestone"  
 Pz = Paleozoic limestones and dolomite  
 / 35° = Strike and dip of beds  
 D / U Fault, U on up side



Map showing traces of surface fault rupture, Wasatch fault zone, Utah.  
(adapted from: Van Horn, 1982).



Location map for test pits.  
1:480 scale.

(Source: Base map provided by ESI Engineering, with adaptations by Northern Engineering and Testing, Inc., 1986, and with further adaptations for this report).

<b>Project:</b> Kays Creek landslide near intersection of Fairfield Street and Church Street, Layton, Utah		<b>Requesting Agency:</b> Davis County Flood Control	
<b>By:</b> Mike Lowe	<b>Date:</b> 6-30-86	<b>County:</b> Davis	<b>Job No.:</b> D6
<b>USGS Quadrangle:</b> Kaysville			

At the request of Sid Smith, Director of Davis County Flood Control, an investigation was made of a landslide located in the SW 1/4 SW 1/4 NW 1/4 sec. 15, T. 4 N., R. 1 W. on the north side of Kays Creek near the intersection of Fairfield Street and Church Street in Layton, Utah (attachment 1). The purpose of the investigation was to examine an active landslide which had been reported to Davis County Flood Control on April 28, 1986, and assess the possibility of continued movement on the landslide. The scope of investigation included 6 field inspections (April 28 and 29 and May 3, 5, 9, and 21, 1986), monitoring of the landslide with a Sinco Model 518115 Tape Extensometer which was provided by the Utah Geological and Mineral Survey, a review of pertinent literature, and examination of aerial photographs (1985, 1:24,000 scale). Sid Smith was present during the April 28 field inspection. Bruce Kaliser, State Hazards Geologist with the Utah Geological and Mineral Survey, was present during the April 29 field inspection.

The material involved in the landsliding consists of horizontal, cyclically bedded silts and clays of lacustrine origin and fill placed on these deposits. The cyclically bedded units are offshore sediments (Miller, 1980) deposited during high stands of lakes occupying the Salt Lake Valley during the Bonneville Lake Cycle from about 30,000 to 10,000 years ago (Currey and others, 1984). The fill contains abundant blocks of concrete and asphalt and appears to be thick. The slope on which the failure occurred has been oversteepened by stream downcutting and placement of fill. For your information, a table and diagram illustrating the landslide classification and terminology used in this memo are included (attachment 2).

The initial failure on April 28, 1986, was probably a debris slide predominately in fill. The landslide formed three distinct blocks which moved several feet toward Kays Creek. This movement apparently broke a buried pipe discharging water from the Weber-Davis Canal near the east end of the landslide. Bruce Kaliser noted an area near the west end of the landslide where piping had removed material prior to the landslide event which may have contributed to the subsequent failure. The water from the broken pipe then eroded the bank of Kays Creek near the east end of the landslide creating a nearly vertical scarp and washing large amounts of material into Kays Creek. The slide material did not block the creek but did force the channel to the opposite (south) bank causing a small earth slump in lacustrine deposits on the south side of Kays Creek, directly across from the broken pipe. This slump was first noted on May 5, 1986. Measurements using the tape extensometer indicate that the upper block near the center of the main landslide on the north side of Kays Creek moved about 1 1/2 inches between May 3 and 5, 1986. No other movements on the landslide were detected, although small slumps and raveling continued to occur on the steep scarp above the broken pipe through May 9, 1986.

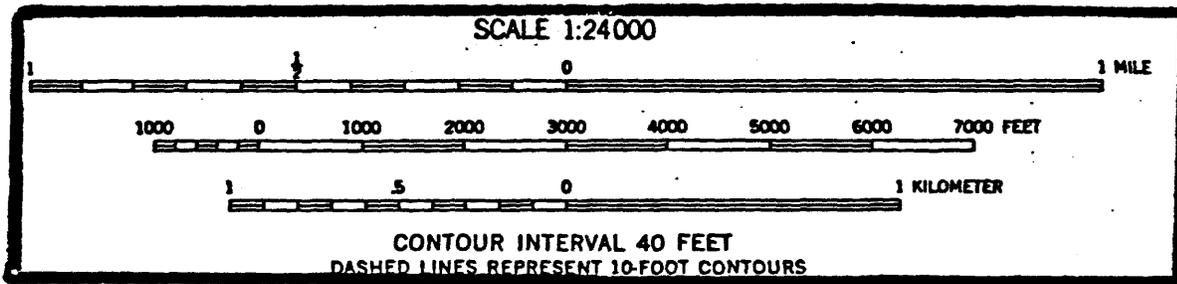
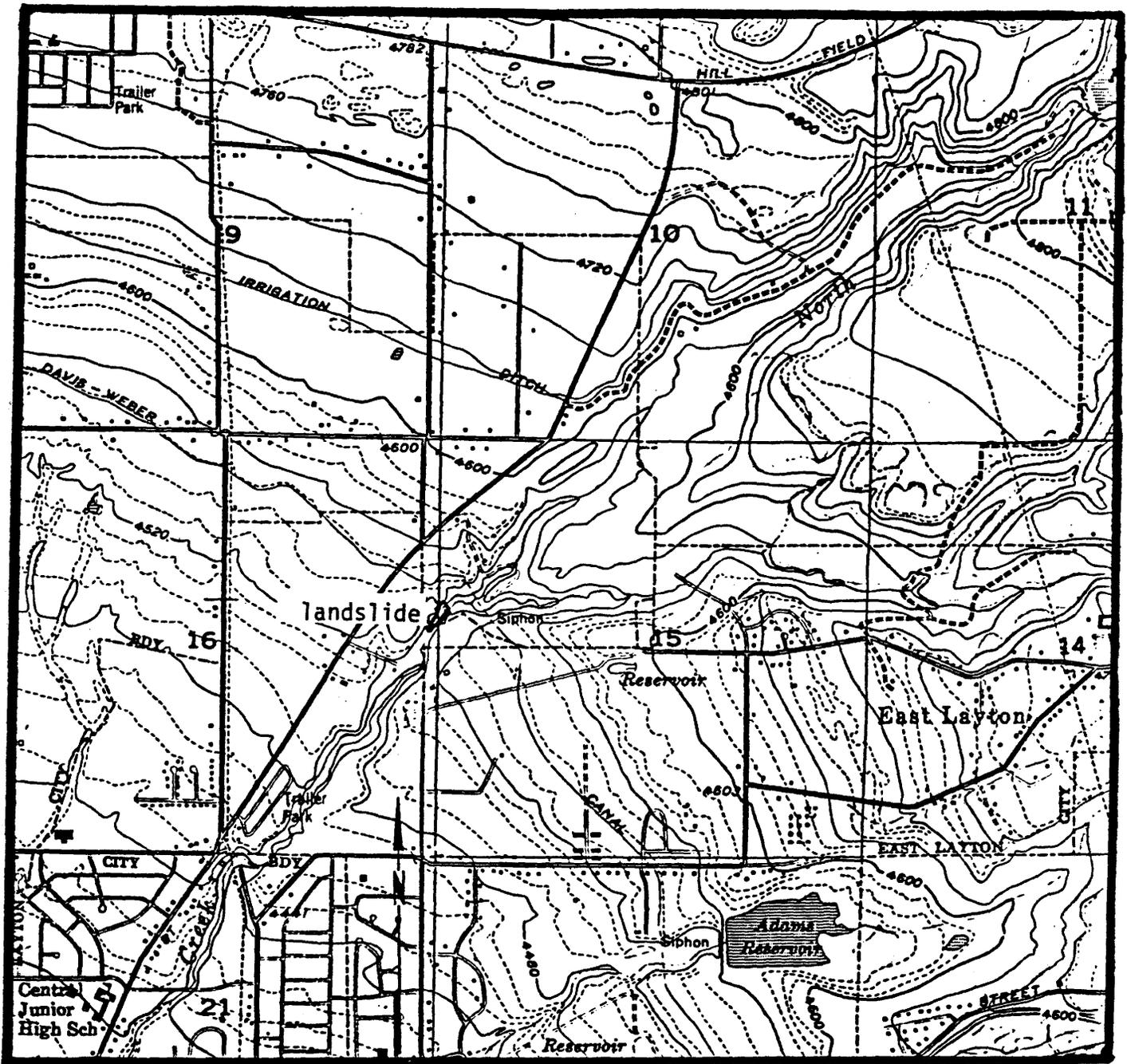
Landslide dimensions were estimated on May 21, 1986. The main scarps of the three blocks are about 350 feet long. Maximum height of the main scarps are as follows: upper block - about 4 feet, middle block - about 3 feet, and lower block - about 1 foot. The scarp heights diminish to near zero at the west end of the landslide. The slide mass is estimated to be about 150 feet long from head to toe. The erosional scarp above the buried pipe is about 25 feet high.

In conclusion, because the scarp above the broken pipe is steeper than the surrounding slopes, and because crown cracks were noted up to 37 feet from this scarp, there is a possibility of further failure at this location. Movement on the landslide at this location will likely break the pipe again causing further erosion and deposition of material into Kays Creek. Should landslide material block the culvert where Kays Creek flows under Fairfield Street, a significant amount of water could be backed up behind the road. This road was not designed to act as a dam and such an event could present hazards to residents downstream. The main landslide mass does not appear to be moving at this time, but could be reactivated during future wet periods. Weight added above the head of the slide could increase the danger of future landsliding, and it is recommended dumping of fill in this area be stopped.

#### REFERENCES

Currey, D. R., Atwood, Genevieve, and Mabey, D. R., 1984, Major levels of the Great Salt Lake and Lake Bonneville: Utah Geological and Mineral Survey Map 73, scale 1:750,000.

Miller, R. D., 1980, Surficial geologic map along part of the Wasatch Front, Salt Lake Valley, Utah: U. S. Geological Survey Map MF-1198, scale 1:100,000.

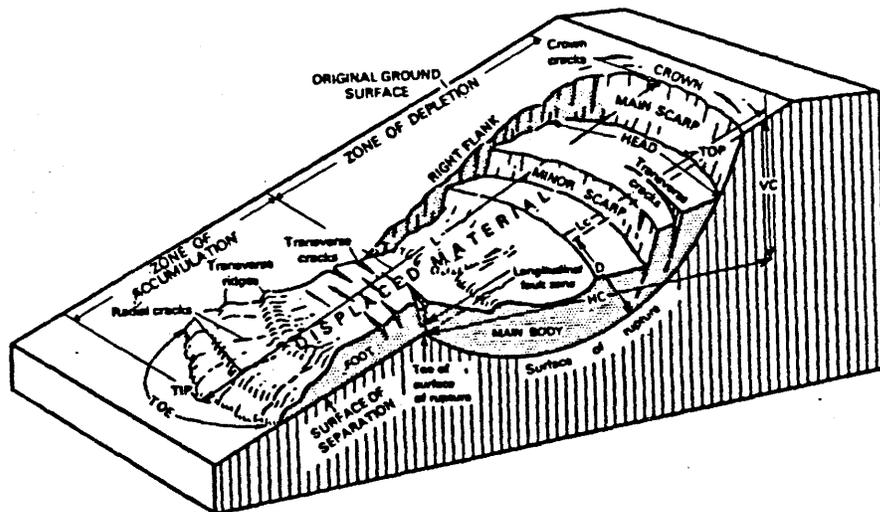


Location Map

Base map from: U. S. Geological Survey 7 1/2 min. topo. quad. Kaysville, Davis County, Utah.

Attachment 2

TYPE OF MOVEMENT			TYPE OF MATERIAL		
			BEDROCK	ENGINEERING SOILS	
				Predominantly coarse	Predominantly fine
FALLS			Rock fall	Debris fall	Earth fall
TOPPLES			Rock topple	Debris topple	Earth topple
SLIDES	ROTATIONAL	FEW UNITS	Rock slump	Debris slump	Earth slump
	TRANSLATIONAL	---	Rock block slide	Debris block slide	Earth block slide
		MANY UNITS	Rock slide	Debris slide	Earth slide
LATERAL SPREADS			Rock spread	Debris spread	Earth spread
FLOWS			Rock flow (deep creep)	Debris flow (soil creep)	Earth flow
COMPLEX			Combination of two or more principal types of movement		



Source:  
 Varnes, D. J., 1978, Slope movements types and processes, in Schuster, R. L., and Krizek, R. J., eds., Landslides, Analysis and Control: National Academy of Sciences, Transportation Research Board Special Report 176, p. 11 - 33.

<b>Project:</b> Preliminary geologic reconnaissance of Davis County property located in the W 1/2 SW 1/4, Sec. 12, T. 1 N., R. 1 W., just south of the Concrete Products Company gravel pits.		<b>Requesting Agency:</b> Davis County Property Manager	
<b>By:</b> Mike Lowe	<b>Date:</b> 12-16-86	<b>County:</b> Davis	<b>Job No.:</b> D7
<b>USGS Quadrangle:</b> Salt Lake City North			

The purpose of this memorandum is to propose a preliminary evaluation of the Davis County property located in the W 1/2 SW 1/4 sec. 12, T. 1 N., R. 1 W., just south of the Concrete Products Company gravel pits, to determine the need for detailed investigations to evaluate gravel resources at the site. The scope of investigation for this memorandum included a three-hour field investigation of the site on December 16, 1986, examination of aerial photographs (1985, 1:24,000 scale), and a review of pertinent geologic literature, including a Dames & Moore (1985) report for areas immediately north and east of the Davis County property. Davis County is interested in selling the property and in order to determine the value of the property, the extent of minable gravel deposits must be determined. The economic feasibility of mining gravel deposits depends on the thickness and quality of the gravel (poorly graded gravels are most desirable), and the presence and thickness of unminable overburden.

Depth to bedrock is expected to be the primary factor controlling the thickness of minable gravel deposits on the property. The property is located on the Salt Lake salient which is a mass of bedrock protruding westward from the Wasatch Range into the Salt Lake Valley. The salient existed during Lake Bonneville time and probably had a significant effect on depositional processes in the lake. The salient was an erosional headland during much of the Bonneville lake cycle, and thus was not a site of deposition of thick shoreline gravels. It is anticipated that bedrock will be encountered at shallow depths over much of the area. Pre-Lake Bonneville drainages on the salient were possible areas of deposition, but these drainages have generally been reoccupied during post-Lake Bonneville time and deposits have been removed due to erosion. Lake deposits on the Davis County property are, therefore, likely to be generally thin, and probably reach their greatest thickness in the northern part which is furthest from the crest of the salient.

During the field inspection a number suspected bedrock outcrops were identified on the Davis County property. Two types of bedrock were identified. Northeast of the pipeline road, tuffaceous mudstone, siltstone, and sandstone is the predominant rock type; southwest of the pipeline road well-cemented conglomerate is predominant. These findings agree in general with Van Horn (1981) as shown on attachment 1. It appears, however, that the tuffaceous mudstone, siltstone, and sandstone unit contact may be slightly further southwest than shown on attachment 1. Dames & Moore (1985) encountered tuffaceous bedrock at depths ranging from 5 to 15 feet to the north and east of the Davis County property. This also supports the hypothesis that bedrock will be encountered at shallow depth on the Davis County property.

Elevation is likely to be the primary factor controlling the distribution and quality of gravel deposits. Poorly graded (well sorted) gravels were deposited primarily at shoreline elevations. In general, the longer the lake stood at a given

elevation, the thicker the gravel deposits. Attachment 2 is a map showing the expected distribution of surficial deposits on the Davis County property. This map was enlarged 10 times from Van Horn's (1982) 1:24,000 scale map which was not meant to provide site-specific information and some inaccuracies in contact locations should be expected. It does, however, illustrate the type of surficial deposits which are found on the property.

Attachment 2 indicates that two types of deposits are predominant. The highest quality gravel deposits are represented by the shaded area labeled bpgy. These are nearshore gravels and sands which were deposited when the lake stood at the Provo Shoreline. Lake Bonneville occupied this elevation for approximately 1,000 years (Currey and Oviatt, 1985), and in some areas, poorly graded gravel deposits of this age may be quite thick.

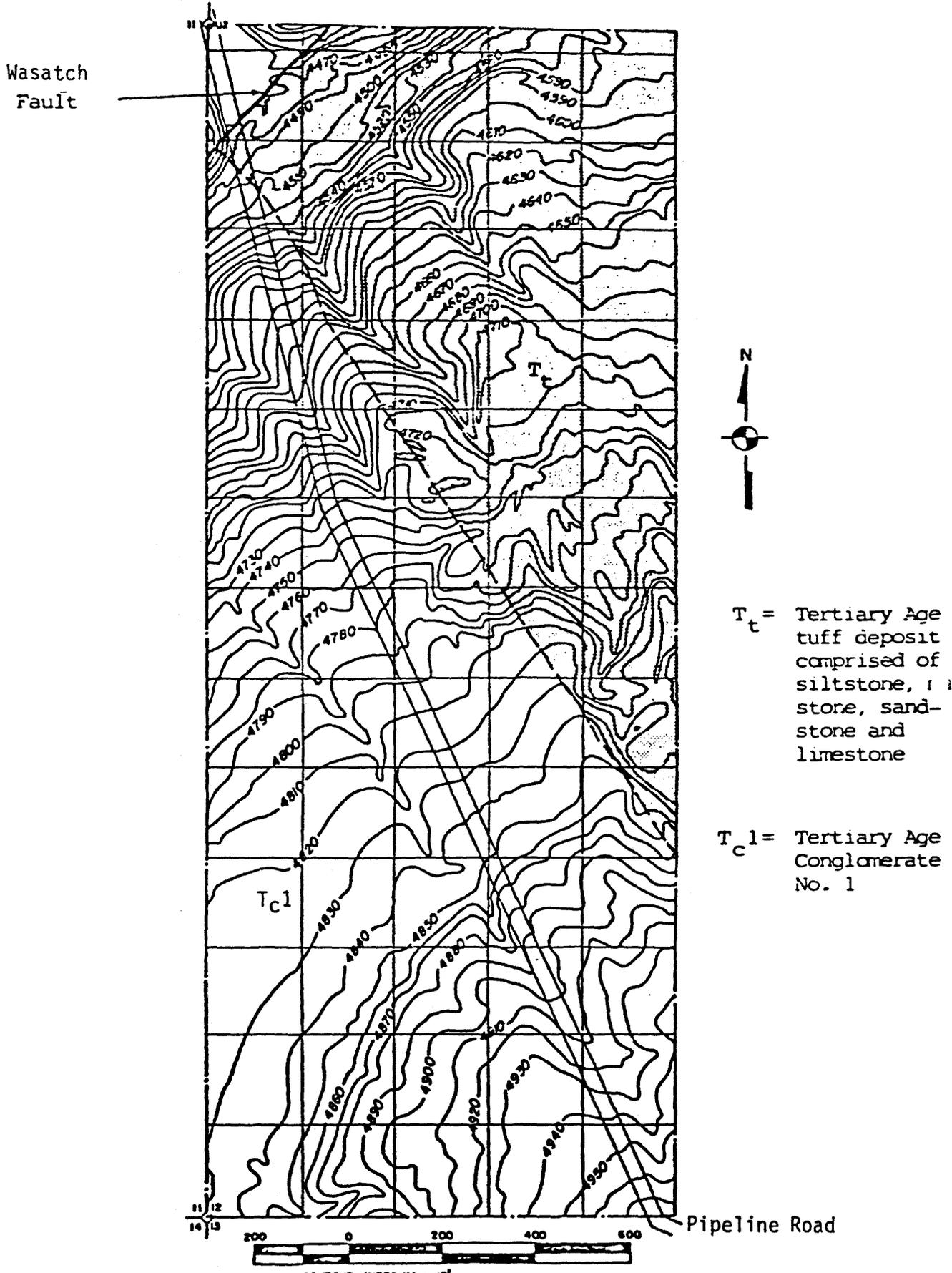
The southeast and northwest ends of the property are covered predominantly with deposits labeled Ig in attachment 2. The deposits of this unit in the southeast are above the Provo Shoreline, but those in the northwest are below the Provo Shoreline. Sediments at the surface in the southeast part of the property were deposited when Lake Bonneville stood at its highest level (Bonneville Shoreline, about 5,200 feet in elevation) before dropping to the Provo Shoreline, and at that time the property was under several hundred feet of water. Fine-grained sediment was typically deposited in such deep water, and exposure 4 (attachment 2) contained mostly sand and silt, with very little gravel. This fine-grained deposit may cover most of the surface in the southeast end of the property, but may be underlain by gravel deposited during the Lake Bonneville transgression. If so, the thickness of the overlying finer-grained deposits is an important factor as this represents unminable overburden.

Deposits at the surface in the areas labeled Ig in the northwest end of the property consist primarily of Provo and post-Provo Shoreline gravel and sand. These sediments probably overlie the same deep-lake silt and sand and Bonneville transgressive gravel and sand found in the southern part of the property. Exposures 1 through 3 contained primarily poorly graded, moderately cemented cobbles and gravels, at least 10 feet thick.

In conclusion, gravel deposits on the property are expected to be thin, but this should be verified. Lake deposits are likely thinnest in the southern part of the property and probably thicken to the north. Three types of deposits form most of the unconsolidated cover on the property. The characteristics of these deposits need to be better determined to evaluate the potential for minable gravel on the property. It is recommended that four backhoe test pits be excavated at the approximate locations shown on attachment 2 to determine the thickness and characteristics of unconsolidated deposits at those locations. The results of this investigation, which would require the time of the County Geologist and a Davis County backhoe and backhoe operator, will be used to determine if a more extensive gravel reserve investigation should be undertaken. If uses other than mining, such as residential development, are anticipated for this property, it is recommended that a complete geologic hazards evaluation be performed. The Wasatch fault crosses the northwestern corner of the property (attachment 1). Please notify me of your decision.

## REFERENCES

- Currey, D. R., and Oviatt, C. G., 1985, Durations, average rates, and probable causes of Lake Bonneville expansions, stillstands, and contractions during the last deep-lake cycle, 32,000 to 10,000 years ago, in Kay, P. A., and Diaz, H. F., eds., Problems of and prospects for predicting Great Salt Lake levels, Conference Proceedings, Center for Public Affairs and Administration: Salt Lake City, Utah, University of Utah, p. 9-24.
- Dames & Moore, 1985, Report, engineering geology and earthwork study, proposed primary road alignment (within a portion of section 12), North Salt Lake, Davis County, Utah, for Granada Inc.: Unpublished consultant's report, 24 p.
- Delta Geotechnical Consultants Inc., 1986, Geotechnical engineering services, proposed development of 60-acre parcel, T1N-R1W - Section 12, Davis County, Utah: Unpublished consultant's proposal, 4 p.
- Van Horn, Richard, 1981, Geologic map of pre-Quaternary rocks of the Salt Lake City North Quadrangle, Davis and Salt Lake Counties, Utah: U. S. Geological Survey Miscellaneous Investigations Map I-1330, 1:24,000 scale.
- Van Horn, Richard, 1982, Surficial geologic map of the Salt Lake City North Quadrangle, Davis and Salt Lake Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Map I-1330, 1:24,000 scale.



Geologic map showing Tertiary bedrock units underlying unconsolidated deposits on Davis County property (enlarged and adapted from Van Horn, 1981 by Delta Geotechnical Consultants Inc., 1986, with additional modifications for this report)

Explanation \*

dg = Post-Provo Shoreline stage of Bonneville lake cycle cobbly sand and gravel, 3 feet to more than 12 feet thick.

bpgy = Provo Shoreline stage of Bonneville lake cycle cobbly gravel and sand with occasional thin beds of silt

bm = Bonneville Shoreline stage of Bonneville lake cycle sandy silt and silty clay.

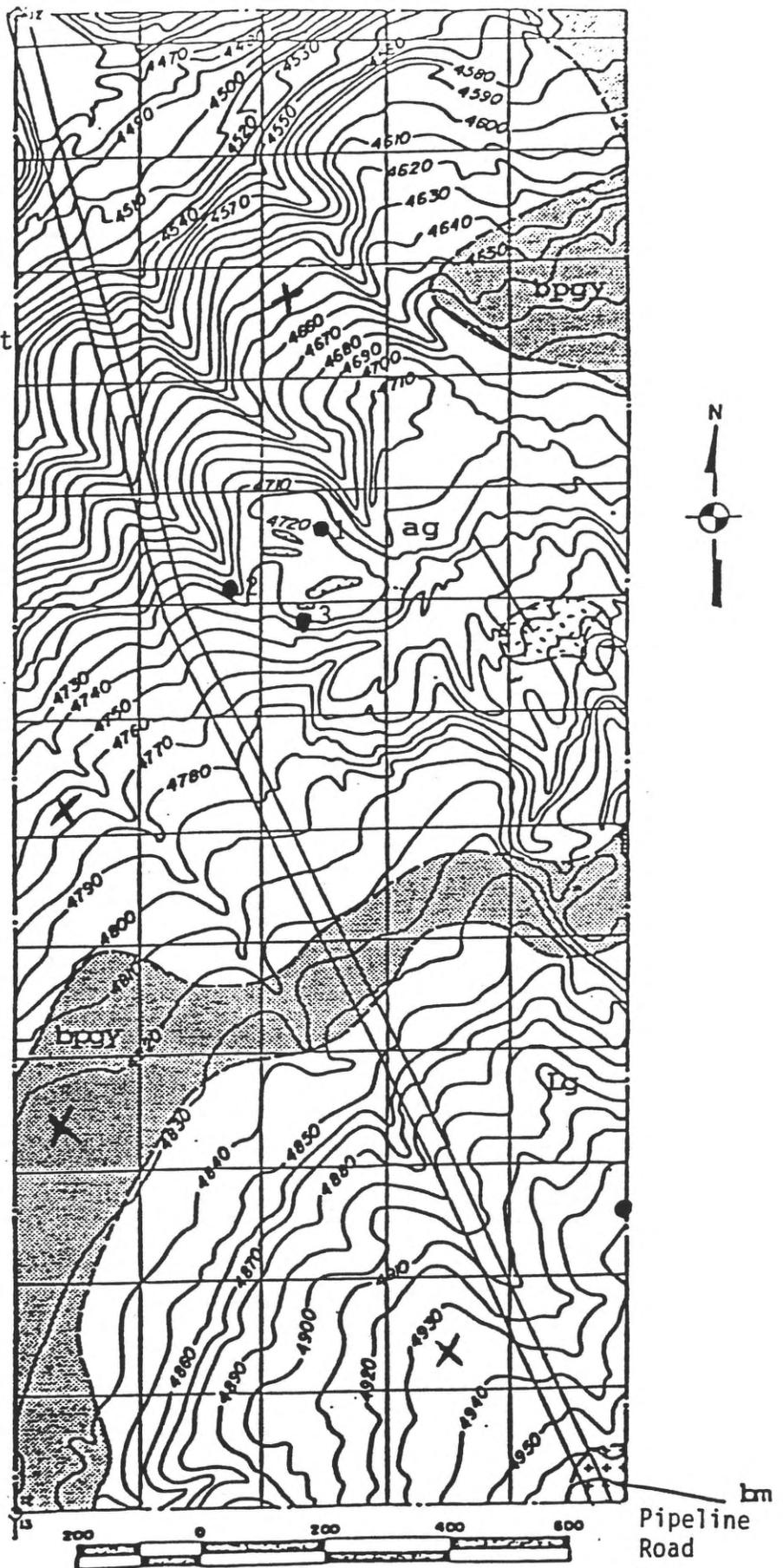
Lg = Undifferentiated lake deposits of Little Valley? lake cycle and Bonneville lake cycle.

ag = Little Valley lake cycle? cobbly gravel and sand.

● 1 Exposure examined during field inspection.

✕ Proposed test pit location.

\* Note: Unit descriptions have been changed from Van Horn's (1982) descriptions to reflect modern Bonneville lake cycle concepts. No additional field work was undertaken to verify this mapping.



Geologic map showing Quaternary unconsolidated deposits on Davis County property and the location of proposed test pits to evaluate potential gravel reserves (enlarged and adapted from Van Horn, 1982, by Delta Geotechnical Consultants Inc., 1986, with additional modifications for this report).

<b>Project:</b> Addendum to preliminary geologic reconnaissance of Davis County property located in the W 1/2 SW 1/4, sec. 12, T. 1 N., R. 1 W., just south of the Concrete Product Company gravel pits.		<b>Requesting Agency:</b> Davis County Property Manager	
<b>By:</b> Mike Lowe	<b>Date:</b> 3-13-87	<b>County:</b> Davis	<b>Job No.:</b> D8
<b>USGS Quadrangle:</b> Salt Lake City North			

## INTRODUCTION

The geology of the Davis County property located in the W 1/2 SW 1/4 sec. 12, T. 1 N., R. 1 W., was summarized in a previous memorandum (Lowe, 1986). In that memorandum, it was proposed that the County Geologist perform a preliminary evaluation of potential gravel resources on the property to determine if more extensive evaluations proposed by geotechnical consulting firms (Chen & Associates, Delta Geotechnical Consultants, Inc.) should be conducted. The results of that preliminary evaluation are presented in this addendum. The scope of work included a 4-hour field investigation on February 23, 1987, and a 2-hour field investigation on March 12, 1987. Barry Burton, Davis County Planner, was present on March 12. On February 23, 5 test pits were excavated and logged. The approximate location of the test pits were plotted in the field on a 1:2,400 scale 1983 aerial photograph with contours. During the March 12 field investigation, six new excavations of unknown origin were discovered in the northern portion of the property. These excavations were examined in the field and the approximate location later plotted on a 1:2,400 scale aerial photograph with contours.

## RESULTS

Attachment 1 shows the approximate location of exposures, test pits, and excavations on the Davis County property. The characteristics of the four exposures were reported in the Lowe (1986) memorandum. Attachment 2 is a hydrograph of Lake Bonneville which explains terminology used in the following discussion. The soil characteristics and geologic interpretations of the backhoe test pits and excavations of unknown origin are:

### Test Pit 1

0 - 5 feet, silt and clay

5 - 13 feet, beds of silt and clay alternating with beds of fine to medium gravel. Approximately 20 to 25 percent gravel.

---

13 feet total depth.

The five feet of silt and clay at the surface is interpreted to be Bonneville Shoreline stage offshore deposits. The underlying 8 feet of interbedded silt, clay, and gravel represents Bonneville lake-cycle transgressive

phase nearshore and offshore deposits which reflect changes in lake level and seasonal variations in sediment load.

Test Pit 2

0 - 11 feet, unbedded silt and sand containing approximately 10 percent matrix-supported fine and medium gravel.

---

11 feet total depth.

This unbedded silt and clay is interpreted to be post-Bonneville lake-cycle slopewash and colluvium derived from the Provo Shoreline escarpment which is located southeast of the test pit. The base of the Provo Shoreline escarpment has an approximate elevation of 4,850 feet.

Test Pit 3

0 - 4 feet, unbedded silt and sand with approximately 10 percent matrix-supported fine and medium gravel.

4+ feet, bedrock, backhoe refusal.

---

4 feet total depth.

The unbedded silt and clay is interpreted to be post-Bonneville lake-cycle slopewash and colluvium derived from the Provo Shoreline escarpment to the southeast. Evidently this area was an erosional headland during the Provo Shoreline stage of the Bonneville lake cycle, and nearshore sediments were not deposited.

Test Pit 4

0 - 4 feet, poorly-graded, well-stratified, fine to medium gravel.

4+ feet, bedrock, backhoe refusal.

---

4 feet total depth.

These well stratified gravels are interpreted to be Provo Shoreline stage nearshore deposits.

Test Pit 5

0 - 10 feet, well-stratified, interbedded sand, gravel, and cobbles.

10 - 11 feet, unconsolidated, unstratified, reddish, silt and sand.

---

11 feet total depth.

The interbedded sands and gravels are interpreted to be Bonneville lake-cycle regressive phase nearshore deposits. The underlying reddish silt and sand is interpreted to be weathered bedrock.

#### Excavations of unknown origin, northern group

In these excavations, bedrock was encountered at depths of three to five feet. Sediments at the surface were predominantly Bonneville lake-cycle regressive phase nearshore gravels and sands.

#### Excavations of unknown origin, southern group

In these excavations (5 to 10 feet deep), bedrock was not encountered. Sediments were predominantly poorly-graded, well-stratified, Bonneville lake-cycle regressive phase nearshore gravels which are well cemented in some areas.

#### CONCLUSIONS AND RECOMMENDATIONS

Gravel deposits in the southern half of the Davis County property are thin or mixed with large quantities of silts and sands. There is no indication that minable gravel is present on this portion of the property. The landscape in this portion of the property has only been slightly modified by man.

The thickness of gravel deposits in the northern half of the property ranges from 0 to more than 10 feet. Areas where gravel deposits are more than feet thick appear to be limited. It is unlikely that these deposits can be economically mined as part of a large-scale operation. Davis County could use the thicker deposits as a source of gravel for county projects, however. The landscape in the northern portion of the property has been largely altered by man.

Based on this preliminary evaluation of potential gravel resources on the Davis County property, it appears that significant gravel resources do not exist on the property. It is therefore recommended that the more extensive investigations proposed by geotechnical consulting firms not be funded by Davis County and that other uses of the property be considered. Geologic hazards should be considered in planning any development on the property. If permanent structures are considered for the northern portion of the property, the Wasatch fault should be accurately located so structures are not placed in the zone of deformation associated with the fault.

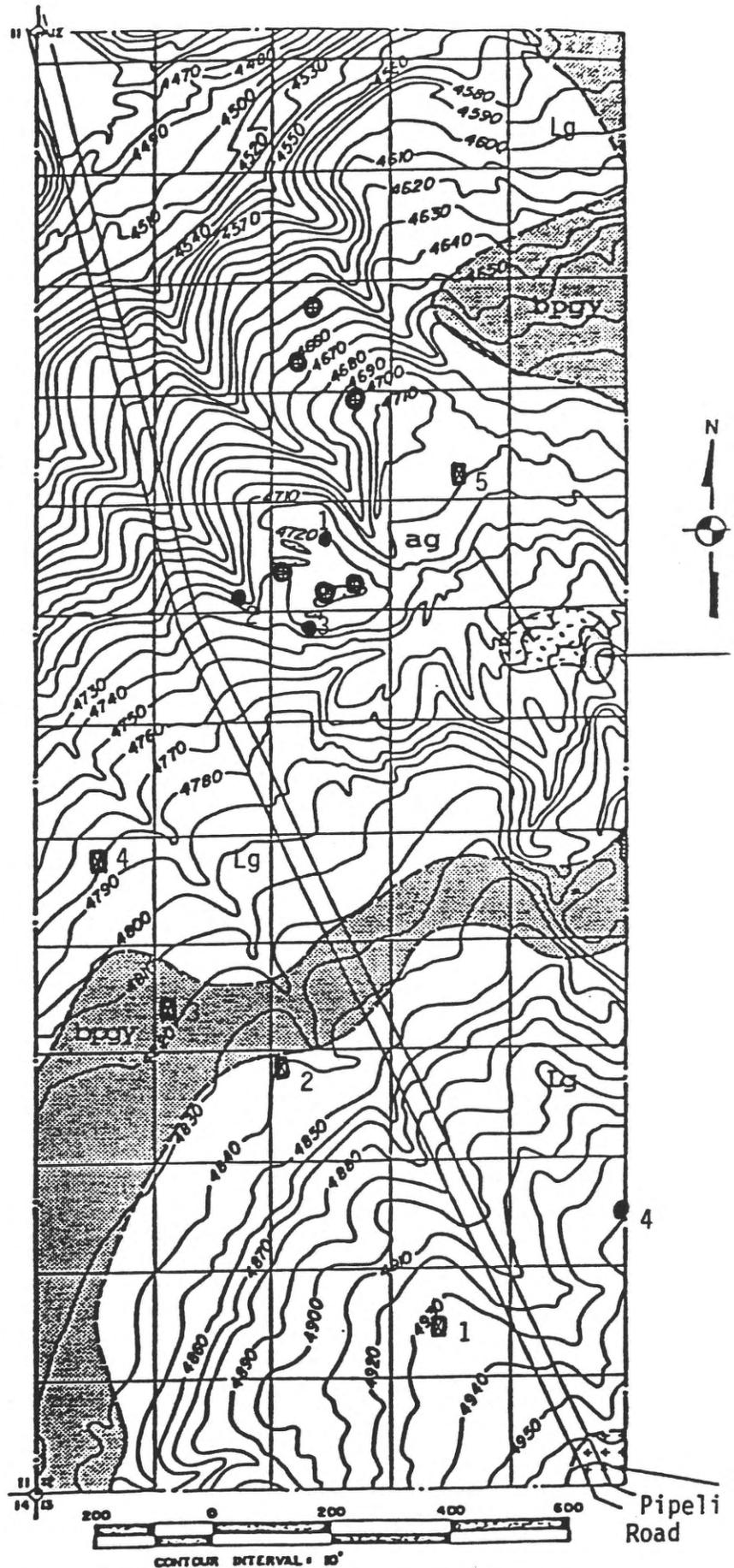
#### REFERENCES CITED

Lowe, Mike, 1986, Preliminary geologic reconnaissance of Davis County property located in the W 1/2 SW 1/4 sec. 12, T. 1 N., R. 1 W., just south of the Concrete Products Company gravel pits.

Explanation \*

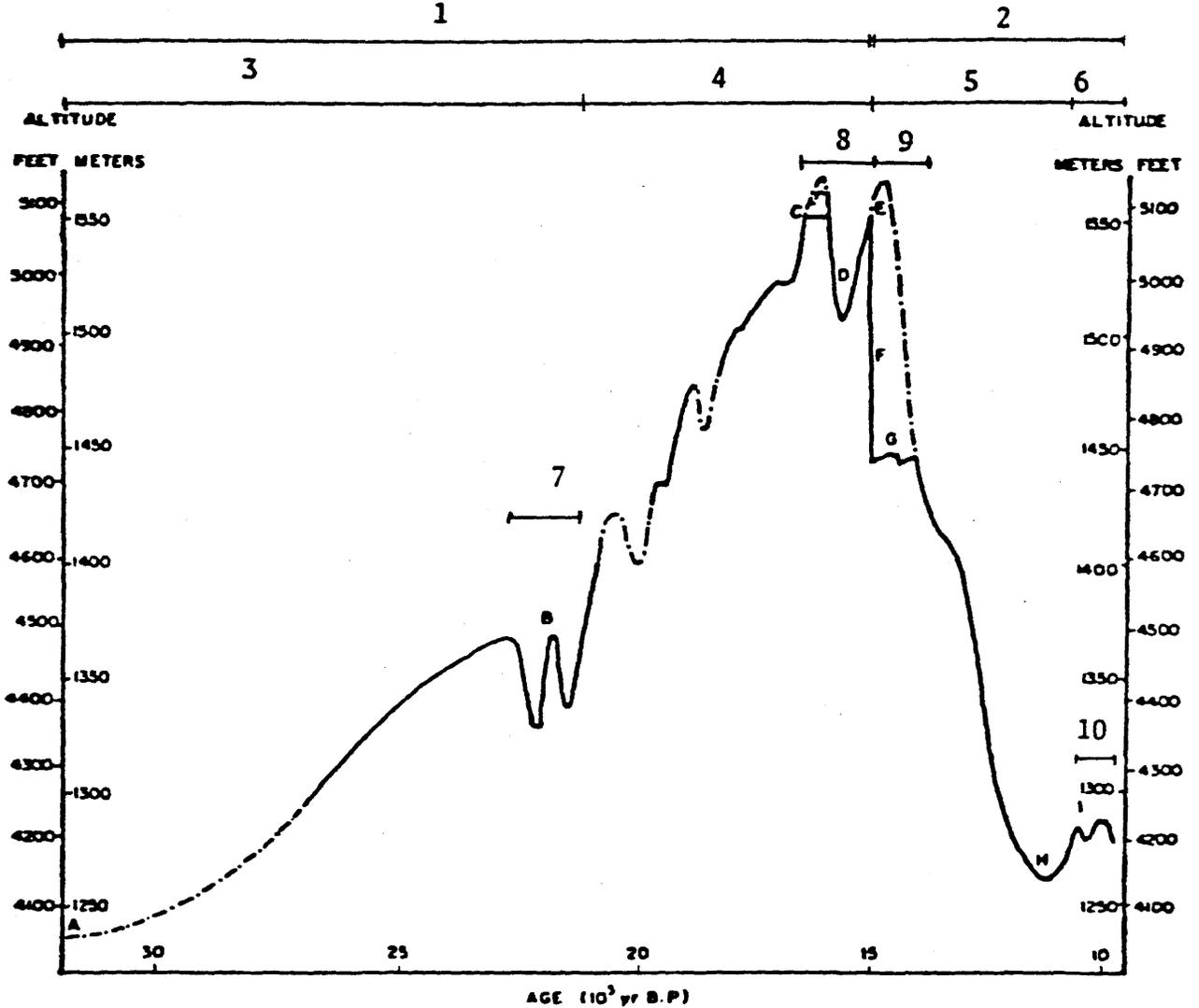
- dg = Post-Provo Shoreline stage of Bonneville lake cycle cobbly sand and gravel, 3 feet to more than 12 feet thick.
- bpgy = Provo Shoreline stage of Bonneville lake cycle cobbly gravel and sand with occasional thin beds of silt.
- bm = Bonneville Shoreline stage of Bonneville lake cycle sandy silt and silty clay.
- Lg = Undifferentiated lake deposits of Little Valley? lake cycle and Bonneville lake cycle.
- ag = Little Valley lake cycle? cobbly gravel and sand.
- 1 Exposure examined during field inspection on December 16, 1986.
- ☒ Approximate test pit location, excavated February 23, 1987.
- ⊕ Approximate location of new excavations of unknown origin, discovered March 12, 1987.

\* Note: Unit descriptions have been changed from Van Horn's (1982) descriptions to reflect modern Bonneville lake cycle concepts. No additional field work was undertaken to verify this mapping.



Geologic map showing Quaternary unconsolidated deposits on Davis County property and the location of proposed test pits to evaluate potential gravel reserves (enlarged and adapted from Van Horn, 1982, by Delta Geotechnical Consultant Inc., 1986, with additional modifications of this report).

- 1- Bonneville lake cycle transgressive phase.
- 2- Bonneville lake cycle regressive phase.
- 3- Stansbury deposits.
- 4- Bonneville deposits.
- 5- Provo deposits.
- 6- Gilbert deposits.
- 7- Stansbury Shoreline stage.
- 8- Bonneville Shoreline stage.
- 9- Provo Shoreline stage.
- 10- Gilbert Shoreline stage.



Hydrograph of Lake Bonneville (adapted from Currey and Oviatt, 1985). Numbers show time periods of terminology.

<b>Project:</b> Geology and geologic hazards, North Davis Refuse District disposal site area, Davis County, Utah		<b>Requesting Agency:</b> Davis County Commission	
<b>By:</b> Mike Lowe	<b>Date:</b> 1987	<b>County:</b> Davis	<b>Job No.:</b> D9
<b>USGS Quadrangle:</b> Kaysville			

The North Davis Refuse District (NDRD) disposal site area, hereafter referred to as "the study area", includes both the landfill and burn plant sites (figure 1). The purpose of this report is to identify geologic hazards affecting the study area, describe the subsurface geology of the area so that the proper locations and depths of upgradient and leachate monitoring wells may be evaluated, and determine the study area for a proposed slope stability evaluation of refuse which has been placed in a small drainage in the northern portion of the landfill site. The study area is located in the Ogden Valley Segment of the Wasatch Front Valleys Section of the Basin and Range Physiographic Province (Stokes, 1977). The Ogden Valley Segment is a north-south trending structural trough which has been the site of accumulation of great thicknesses of sediment since its inception in early Tertiary\* time about 43.6 million years ago (Eardley, 1955). The Wasatch Range and the west-dipping Wasatch fault bound the trough to the east, and geophysical data indicate that Little Mountain may be part of a horst which bounds the trough to the west (Feth and others, 1966). The sediments filling the trough are predominantly of fluvial, lacustrine, and deltaic origin. Geophysical data indicates that, in some areas, these sediments may be as much as 6,000 to 9,000 feet thick (Feth and others, 1966).

#### Quaternary Geologic History

The study area is located in a closed hydrologic basin, called the Lake Bonneville basin, and water flowing into this basin generally leaves the basin only by evapotranspiration. The Lake Bonneville basin has been an area of internal drainage for much of the last 15 million years, and lakes of varying sizes likely existed in the area during all or most of that time (Currey and others, 1984). Figure 2 is a schematic diagram showing the approximate time periods of, and the approximate elevations reached during, the last three lake cycles in the Lake Bonneville basin.

The first lake cycle shown on figure 2, which inundated the study area, is called the Little Valley lake cycle. This lake cycle occurred sometime between about 150,000 years ago and 90,000 years ago (Scott and others, 1983). It is likely that during the Little Valley lake cycle, the study area was the site of accumulation of sediments deposited into the lake by the Weber River, and that part of the sediment mass below the study area is made up of sediments of this age. No sediments of Little Valley lake cycle age, however, are exposed to verify this.

The next to the last lake cycle in the Lake Bonneville basin, the Cutler Dam lake cycle, occurred sometime around 75,000 years ago (Oviatt and others, 1985). Work on this lake cycle is in preliminary stages and it is not known if this lake reached the elevation of the study area.

In the latter part of Pleistocene time, from about 32,000 years before present to about 10,000 years before present, a lake with a maximum depth of at least 1,000 feet covered an area of about 20,000 square miles in what is now northwestern Utah, northeastern Nevada, and southeastern Idaho (Currey and others, 1984). This lake was named Lake Bonneville, and the period of time occupied by the rise and fall of this lake is called the Bonneville lake cycle (Scott and others, 1983). Figure 3 is a hydrograph of Lake Bonneville which illustrates the terminology used in describing Bonneville lake-cycle events in this report.

The part of the Bonneville lake cycle during which the lake slowly rose from the pre-Lake Bonneville interlacustrine low stand to its high stand at the Bonneville Shoreline (approximately 5,200 feet) is defined as the Bonneville lake cycle transgressive phase (1 of figure 3). This transgression occurred from about 32,000 to 15,000 years before present (Currey and Oviatt, 1985). Bonneville deposits (4 of figure 3) refer to those sediments deposited in Lake Bonneville during the transgressive phase between about 20,000 and 15,000 years ago at elevations presently below about 5,200 feet. A great thickness of offshore silts and clays which settled out of quiet water was deposited in the region during this time. About 16,400 years ago Lake Bonneville reached an external threshold near Zenda in southeastern Idaho (Currey and Oviatt, 1985).

This threshold control persisted at least intermittently for about 500 years, and the Bonneville Shoreline (C of figure 3) was developed during this period (Currey and Oviatt, 1985). A temporary drop in lake level called the Keg Mountain oscillation (D of figure 3) occurred from about 15,900 to 15,000 years ago, after which the lake rose once more to the elevation of the Zenda threshold (E of figure 3). The threshold was then destroyed (F of figure 3) by about 355 feet of downcutting and 2 miles of headward erosion, probably in less than a year, dropping the level of the lake to about 4,800 feet and ending the Bonneville lake cycle transgressive phase (Currey and Oviatt, 1985).

At the end of the Bonneville Flood, a new threshold was established in the vicinity of Red Rock Pass, and the lake stabilized, forming the Provo Shoreline (G of figure 3) at an elevation of about 4,800 feet (Currey and Oviatt, 1985). The lake apparently occupied this level until about 14,000 years ago when climatic conditions caused a slow drop in lake level (Currey and Oviatt, 1985). The part of the Bonneville lake cycle during which the lake slowly regressed from the Provo Shoreline, from about 15,000 to about 10,000 years before present, is here defined as the Bonneville lake cycle regressive phase (2 of figure 3). Provo deposits (5 of figure 3) are defined as those sediments deposited while Lake Bonneville stood at the Provo Shoreline, and those sediments deposited during the slow recession from about 14,000 to 11,000 years ago. Provo deposits in the study area consist primarily of deltaic gravel and sand which form a cap over the Bonneville offshore silt and clay. These sediments form the flat surface upon which both Washington Terrace and the study area have been constructed. The Provo delta of the Weber River is the largest delta constructed into Lake Bonneville (Feth and others, 1966).

During the last 10,000 years (post-Lake Bonneville time), fluvial erosion, fluvial deposition, and landsliding have been the dominant geologic processes in the study area. As Lake Bonneville slowly receded from the Provo Shoreline, the Weber River cut down and eroded laterally into the Weber River Delta until the

river reached its present elevation and gradient. During this process, fluvial sands and gravels were deposited over pre-existing sediments. The fluvial erosion created the steep bluffs which are presently found on both sides of the Weber River near the study area. These steep bluffs have been the site of both prehistoric and historic landsliding.

### Surficial Geology

Figure 4 is a surficial geologic map of a portion of northern Davis County. Mapping was accomplished by air photo interpretation using 1985 1:24,000 scale photos. Mapping has not been field checked. Previous maps which included the study area (Miller, 1980; Feth and others, 1966; and Van Horn, 1975) were examined and aided in the air photo interpretation for this study. Map units have been reinterpreted using modern concepts concerning Lake Bonneville geologic history. Surficial deposits in the study area include five types: Bonneville lake-cycle lacustrine sediments (offshore and deltaic) and post-Lake Bonneville fluvial, alluvial-fan, eolian, and landslide deposits.

The oldest sediments exposed in the study area are Bonneville offshore deposits. These are predominately silt, clay, and sand which settled to the lake bottom in offshore quiet water when Lake Bonneville stood at its highest level about 16,400 to 15,000 years ago. These sediments are covered by Provo deltaic deposits and post-Lake Bonneville eolian sands. These Bonneville offshore deposits are well stratified and sorted. Although covered by younger sediments in most of the study area, these deposits have been exposed by fluvial erosion and landsliding along the upper part of the bluff above the Weber River in the northern portion of the study area.

The next oldest sediments in the study area, Provo deltaic cobbles, pebbles, and sands, cover the Bonneville offshore sediments. These coarse-grained sediments were deposited where the Weber River flowed into Lake Bonneville when the lake stood at the Provo level, forming a triangle-shaped bench with the apex of the triangle at the mouth of Weber Canyon. These sediments are exposed in the western portion of the study area, but in most of the area they have been covered by post-Lake Bonneville eolian sand.

Post-Lake Bonneville older Holocene fluvial deposits form terraces along the drainage of the Weber River in the northeast portion of the study area. The highest and oldest terrace is found at the bottom of the bluffs in the northeast portion of the study area. This terrace has been covered in most areas by alluvial fan deposits, colluvium, and landslides. A slightly younger terrace is found further north at slightly lower elevations. These deposits of gravel, cobbles, and sand are older and generally topographically higher than modern (younger Holocene) deposits of the Weber River which are found further north, nearer to the river. Younger Holocene fluvial deposits are not found in the study area. Near the mouth of Weber Canyon, the post-Lake Bonneville Weber River deposits appear to lie directly upon pre-Lake Bonneville fluvial deposits (Feth and others, 1966). Apparently all Bonneville lake-cycle deposits have been eroded away as the Weber River cut down through its Provo delta to reach its present elevation.

Post-Lake Bonneville alluvial-fan deposits are found along the northern portion of the study area at the mouths of drainages. The alluvial fans have been grouped into two age categories based on morphology and crosscutting

relationships. The older Holocene fans are generally inactive. Deposition periodically occurs on the younger Holocene fans. Alluvial-fan deposits vary from well to poorly sorted and grain size ranges from clay to boulders.

Post-Lake Bonneville landslide deposits are found along the bluff above the Weber River in the northern portion of the study area. The oversteepened slopes along which the landslides occur were created by downcutting and lateral erosion of the Weber River into its Provo delta as Lake Bonneville slowly retreated to lower levels.

Post-Lake Bonneville eolian sand deposits form northeast/southwest trending longitudinal dunes which cover Provo deltaic deposits in most of the study area. Cross bedding of the type commonly associated with eolian deposits was observed in the foundation excavation for a Layton City water tank on February 10, 1986. Lacustrine nearshore sands west of the study area may be a possible source for the sand.

### Subsurface Geology and Ground-Water Hydrology

Little information is available concerning the subsurface in the study area. Figure 5 shows the location of cross section NW shown in figure 6. This cross section is part of a ground-water recharge study by Clyde and others (1984) and shows the top of the Sunset and Delta aquifers, the bottom of the Delta Aquifer, and underlying and adjoining coarse-grained deposits at the mouth of Weber Canyon which are believed to be hydraulically connected to the Delta Aquifer. These hydrogeologic units will be used as a framework for discussing the subsurface geology of the study area.

The basin in the northern Davis County area is underlain at great depths by well-consolidated rocks of Precambrian and Paleozoic age. The top of these rocks form the floor of the basin which is deepest near Ogden, becoming more shallow toward the Pleasant View salient to the north and toward Farmington to the south as shown in figure 7 (cross section A-A') (Feth and others, 1966). Geophysical data suggest that the thickness of the valley fill reaches a maximum of 6,000 to 9,000 feet in the middle of the basin a few miles west of Ogden, and that it ranges elsewhere from a feather edge at the mountain front to about 2,500 feet over the bedrock ridges that are thought to enclose the basin to the north, south, and west (Feth and others, 1966). The depth to bedrock under the Weber Delta (upon which the study area is located) is estimated to be approximately 2,500 feet (Clyde and others, 1984). These rocks may be a source of ground-water recharge to the basin, especially along the Wasatch fault zone on the east side (Clyde and others, 1984).

Very little is known about the poorly consolidated and unconsolidated formations that overlie the bedrock and make up the valley fill. Petroleum exploration wells near Farmington penetrated poorly consolidated rocks resembling the Tertiary Salt Lake Formation at depths as shallow as 810 feet (Feth and others, 1966). The upper surface of these rocks appears to dip steeply to the west in the Weber Delta area (Feth and others, 1966). These rocks have little effect upon the principle fresh water aquifers and their regimen of flow (Clyde and others, 1984). The exact position of the subsurface boundary between rocks of Tertiary age and rocks of Quaternary age is not known.

Information concerning pre-Little Valley lake-cycle deposits is provided by

the log of a water well located about 2 miles west of Roy, Utah (Clyde and others, 1984). With the exception of the Delta Aquifer, few gravels or coarse-grained sediments occur in these deposits in the vicinity of this well (Clyde and others, 1984). The sediments below the Delta Aquifer are mainly sands with interbedded clays, silts, and a few streaks of gravel. The proportion of fine-grained sediments increases generally with depth as does the degree of cementation (Clyde and others, 1984). The finer-grained nature of the sediments, the higher proportion of clays, and increased ground-water salinity indicate that formations beneath about 1000 feet conduct relatively small quantities of ground water, at least near the middle of the basin (Clyde and others, 1984).

The Delta Aquifer is an unusually coarse-grained unconsolidated formation that underlies all of the Weber Delta area (Clyde and others, 1984). It is composed mainly of coarse-grained sands and gravels with thin interfingering layers of clay, silt, and sand, but contains some layers described in drillers' logs as boulders and clay (Clyde and others, 1984). The Delta Aquifer probably represents a large alluvial fan of mixed mudflow and braided-streamflow origin which has coalesced with minor alluvial fans and colluvium along the Wasatch Front. It evidently formed near the beginning of a lacustrine cycle as increased precipitation and runoff caused erosion of accumulated alluvial and glacial sediments of the upper Weber Valley (Clyde and others, 1984). It is not known if this lacustrine cycle is the Little Valley lake cycle or an earlier lake cycle as no age dates are available. The uppermost 100 feet (not stippled in the geologic profile, figure 6) of the Delta Aquifer contain deposits which are more lenticular and are finer grained than the main body (stippled in the geologic profile, figure 6) of the aquifer below (Clyde and others, 1984). This uppermost portion of the aquifer probably represents interfingering deposits of the encroaching but widely fluctuating lake interrupting alluvial-fan deposition (Clyde and others, 1984). The Delta Aquifer is hydraulically interconnected to the underlying coarse-grained sediments and to the adjoining wedge of alluvial deposits at the mouth of Weber Canyon (Clyde and others, 1984). The top of the Delta Aquifer is about 500 to 700 feet below the land surface at most places where it has been identified in logs of wells (Feth and others, 1966). The aquifer ranges in thickness from at least 300 feet along the eastern edge to less than 100 feet west of the Weber Delta (Clyde and others, 1984). The Delta Aquifer is probably fully saturated and confined except near the mouth of Weber Canyon.

Sediments above the Delta Aquifer are predominantly fine-grained lacustrine sediments, except near the mouth of Weber Canyon where these sediments were either not deposited or have been subsequently removed. These finer-grained sediments are interrupted by a shallower and less productive water-bearing zone than the Delta Aquifer, called the Sunset Aquifer (Feth and others, 1966). A contour map of the top of the Sunset aquifer indicates that it is not present beneath the study area (Feth and others, 1966). In most places the upper surface of the Sunset Aquifer is 250 to 400 feet below the land surface. Drillers' logs indicate that the aquifer is from 50 to as much as 250 feet thick and consists largely of sand; mixtures of gravel, sand, and silt; or sand and silt (Feth and others, 1966). It is not known if these sediments are pre-Little Valley lake-cycle deposits or pre-Bonneville lake-cycle fluvial deposits and early Bonneville lake-cycle transgressive nearshore deposits as no age dates are available. Like the Delta Aquifer, water in the Sunset Aquifer is under artesian conditions, but the Sunset Aquifer is much less permeable.

The basin fill between elevations of about 4,350 feet and 4,800 is predominantly silt and clay with lesser amounts of sand and gravel. These lacustrine offshore deposits are commonly well laminated and contain interbedded layers of sand and silt (Feth and others, 1966). Figure 8 shows the location of figure 9 which is a topographic profile through the study area upon which the logs of water wells have been plotted. Several of the wells penetrate Weber River Delta deposits, including one in the study area, and show the predominance of fine-grained deposits. These fine-grained offshore deposits are more than 300 feet thick in the study area as shown in figure 9. It is not known if all of these deposits are of Bonneville lake-cycle age or if the lower portion is of Little Valley lake-cycle age. These deposits characteristically have a low permeability and do not allow water to percolate downward into underlying deposits. The water moves downward to the upper surface of a clay unit and then moves laterally to a point of discharge (Feth and others, 1966). Some water does penetrate into the fine-grained offshore deposits forming local bodies of perched water in the interbedded sand and gravel lenses and this water commonly discharges in canyon walls or roadcuts (Feth and others, 1966). Landsliding may be associated with this perched ground water.

Provo deltaic sands, gravels, and cobbles are found capping the delta top in the southwest portion of the study area. These permeable deposits are characteristically 10 to 30 feet thick, although locally they can be 50 to 100 feet thick (Feth and others, 1966). Water falling on or flowing over these deposits percolates down to the top of the offshore silt and clay deposits. A shallow unconfined aquifer probably exists in the lower portion of the Provo deposits in most areas but the depth to the water table is generally not known. These deposits are covered in most of the study area by post-Lake Bonneville eolian sands as shown on figure 9.

The post-Lake Bonneville eolian sands are of variable thickness in the study area. In the southern portion of the study area these deposits may be as much as 150 feet thick (Miller, 1980). Borehole data indicate that the sand is about 60 feet thick near the landfill site in the northern portion of the study area (EMCON Associates, 1982). Like the Provo deltaic sand and gravel, these deposits are very permeable and water falling on the surface where these deposits are found generally percolates downward until reaching the Bonneville offshore silts and clays. Occasional fine-grained lenses are found in these deposits and perched aquifers commonly form above these lenses.

More recent fluvial deposits of variable thickness are found along the drainages of the Weber River. Although the Delta Aquifer has been covered with hundreds of feet of deltaic and other deposits, the apex of the main Delta Aquifer fan near the mouth of Weber Canyon has been reached by the incision of the Weber River (Clyde and others, 1984). This is the primary recharge area for the Delta Aquifer (Clyde and others, 1984).

The direction of ground-water flow in both artesian and water-table aquifers in most of the southern half of the Provo Delta of the Weber River is to the west and southwest. Near the bluff created by fluvial erosion and landsliding, ground water in the water-table aquifer also moves to the north, often along landslide rupture surfaces. Springs along the bluff in the northern portion of the study area indicate a probable northward component to ground water movement in the area of the landfill. Perched ground water may be found above

fine-grained lenses in the eolian deposits. The direction of flow of this perched ground water cannot be predicted.

### Geologic Hazards

Potential geologic hazards in the Wasatch Front area include seismic hazards (ground shaking, surface fault rupture, tectonic subsidence, liquefaction, seismically induced slope failure and/or flooding), slope failures, problem soils, flooding, and shallow ground water. This report presents a preliminary evaluation of potential geologic hazards affecting the study area.

#### Seismic Hazards

The study area is in an active earthquake zone called the Intermountain seismic belt which extends from northwestern Montana to southwestern Utah. In the northern Davis County area, the largest magnitude earthquake during historical time occurred in 1914 and was an estimated Richter magnitude 5.5 (Arabasz and others, 1979). Numerous smaller earthquakes have occurred in the Davis/Weber County area within the last 120 years. Many of these earthquakes cannot be attributed to known active faults, although faults capable of generating earthquakes are present in the area. The Wasatch fault, which trends north-south along the mountain front east of the study area, is the one of most concern because of its recency of movement, potential for generating large earthquakes, and proximity to the study area. It consists of a zone of faults and crustal deformation, sometimes as much as several thousand feet wide, and is considered capable of generating earthquakes up to magnitude 7.0-7.5 (Schwartz and Coppersmith, 1984). Other fault zones, such as the Hansel Valley or East Cache fault zones, are capable of generating earthquakes which could cause ground shaking damage in the study area.

#### Ground Shaking

Ground shaking is the most widespread and frequently occurring seismic hazard and is responsible for the majority of earthquake-caused damage. The extent of property damage and loss of life in an earthquake due to ground shaking are determined by several factors including: 1) strength of seismic waves reaching the surface (horizontal accelerations are the most damaging), 2) the frequency, amplitude, and duration of ground shaking, 3) proximity to fault zones or epicenters, 4) foundation materials, and 5) building design (Costa and Baker, 1981). Foundation materials are important because ground shaking can be amplified by local site conditions, and the site response is influenced by the nature and thickness of underlying unconsolidated deposits (Hays and King, 1982).

The severity of ground shaking is chiefly dependent on the magnitude of the earthquake. Based on expected shaking levels at bedrock sites, the Uniform Building Code (UBC) places the study area in seismic zone 3 and gives minimum specifications for earthquake-resistant design and construction. The Utah Seismic Safety Advisory Council (USSAC) places the study area in seismic zone U-4 and recommends application of UBC zone 3 specifications with more stringent review and inspection to insure compliance.

Both the UBC and USSAC seismic zonations are based on expected ground shaking in bedrock. Unconsolidated deposits commonly amplify ground shaking relative to bedrock, and the degree to which the amplification occurs depends

upon the nature and thickness of the unconsolidated deposits and on the frequency (period) and amplitude of the seismic waves (Hays and King, 1982). It is important to understand that when the fundamental mode of response of a building has the same period as the amplified seismic waves, the potential for high damage levels increases. Short period waves (0.1-0.2 seconds) are most destructive to 1-2 story buildings, whereas waves with 0.2-0.7 second periods are most destructive to 3-7 story buildings. Longer period waves may cause damage to taller buildings with relatively little effect on other structures.

Hays and King (1982) determined that amplification generally increases from the mountains toward the center of the valley for seismic waves of all periods. The specific results for the 0.2-0.7 second period band in the study area are shown in figure 10. The actual values shown in figure 10 represent ratios of horizontal spectral velocities at valley sites relative to bedrock sites. These values can best be understood in terms of damage and level of ground shaking by relating them to the Modified Mercalli (MM) intensity scale (table 1). Robison and others (1986) used the following equation developed by Borcherdt and others (1975) to relate horizontal spectral amplification (AHSA) to MM intensity:

$$I = 0.27 + 2.70 \log (\text{AHSA}),$$

where I is the incremental increase on the MM intensity scale. Applying this relationship to the study area data, the contour lines in figure 10 indicate an incremental increase of 1.7 intensity units for the 3.3 contour. Algermissen and Steinbrugge (1984) assigned a MM intensity of VII for bedrock for the magnitude 7.5 earthquake. Thus, it can be seen that the study area may experience maximum Modified Mercalli intensities between VIII and IX (table 1). Donovan (1981) has determined that ground shaking generated by earthquakes with epicenters within a 10-mile radius of the study area could be even greater, and site specific studies of ground shaking should consider these near-field affects from local earthquake sources as well as amplification due to site conditions.

Significant damage due to ground shaking could occur in the study area in the future. It is therefore recommended that all construction should conform to Uniform Building Code standards for seismic zone 3 with monitoring by regulatory agencies as recommended by the Utah Seismic Safety Advisory Council for their seismic zone U-4. In addition, site-specific ground-shaking studies are recommended prior to the construction of critical facilities, lifelines, schools, and high occupancy or multi-story (>2) buildings.

#### Surface Fault Rupture

Studies along the Wasatch fault zone (Schwartz and Coppersmith, 1984) and elsewhere indicate that the most likely areas for surface fault rupture are along areas of previous (prehistoric) rupture. These areas are identified by mapping fault scarps. Miller (1980) and Van Horn (1975) map a fault with the east side down just east of the eastern boundary of the landfill site at approximately 2400 east. New United States Geological Survey mapping of the Wasatch fault zone indicate that this scarp is not of tectonic origin. The nearest tectonic scarps to the study area are along the Weber segment of the Wasatch fault, about 3,000 feet east of the study area (Nelson, A. R., personnel commun. 1987). There is no evidence of surface fault rupture hazard in the study area.

## Tectonic Subsidence

Large-scale tectonic subsidence may accompany surface faulting during large earthquakes as the downthrown block undergoes regional downdropping and tilting toward the fault (Keaton, J. R., oral commun., July 16, 1986). This subsidence may occur over tens of miles from surface faults. Preliminary tectonic deformation maps for the Wasatch fault indicate that predicted subsidence due to the "characteristic" Wasatch earthquake (Richter magnitude 7.0-7.5) is less than 5 feet in the study area. Flooding caused by tectonic subsidence would occur along the Weber River flood plain and may affect the northern portion of the study area, but will not reach the burn plant or landfill sites. In the study area, tectonic subsidence is most likely to affect tall buildings and gravity-flow systems such as sanitary sewers, storm sewers, and canals.

## Liquefaction

Liquefaction is a phenomenon which may occur during earthquakes of magnitude 5.0 and larger (Kuribayashi and Tatsuoka, 1975, 1977; Youd, 1977). Liquefaction occurs when loose, saturated, fine-sand deposits are subjected to earthquake shaking, causing the loss of essentially all shear strength as pressures are rapidly transferred from the granular structure of the soil to pore water (Anderson and others, 1982). Depending on slope, three types of ground failure are commonly associated with liquefaction (Anderson and others, 1982): (1) flow landslides (slopes steeper than about 5.0 percent), (2) lateral spread landslides (slopes between about 0.5 percent and 5.0 percent), and (3) bearing capacity failures (slopes less than about 0.5 percent). Clays in excess of 15 percent may preclude liquefaction (Anderson and others, 1982), as do confining pressures at depths below about 10 meters (30 feet) (Youd, T. L., oral commun., May 19, 1986). A liquefaction potential map of the study area (figure 11) indicates that the liquefaction potential in most of the study area, including the burn plant site, is very low. Anderson and others (1982) rated the area as very low because the shallow ground-water table was expected to be well below the ground surface. Ground water (probably perched) was encountered during foundation excavation, however, and therefore the liquefaction potential at the site may be higher than mapped. Also, much of the steep bluff above the Weber River is landslide and steep topography. Anderson and others (1982) indicate that much of this area is classified as high liquefaction potential, but it is not known whether the local landslides along the steep bluff were initiated by liquefaction. Paleo liquefaction features were identified in an exposure at the landfill site. It is possible that flow landslides may occur in this area during seismic events. It is therefore recommended that future refuse disposal cells be located away from the edge of this bluff.

## Seismically-induced Slope Failure and/or Flooding

Earthquakes of magnitude 4.0 or greater are generally required to induce slope failure (Keefer, 1984). The role of earthquake ground shaking in initiating slope failures is not well understood and no studies assessing seismic slope stability in the study area have been completed. Those slopes most susceptible to non-seismically induced landsliding are most likely to fail during an earthquake, and it is recommended that all slope stability studies include analyses under seismic conditions during both moderate and large earthquakes. Preliminary seismic slope stability maps of the Kaysville 7.5' Quadrangle indicate that the bluffs in the northern part of the study area have a

high potential for earthquake-induced landslides (Tophan, D. E., oral commun., April 6, 1987). Landsliding will be discussed further in the slope failure section of this report.

Flooding due to earthquake events may result from dam failure, tectonic subsidence, discharge of ground water, and diversion of surface drainage. Earthquake induced flooding in the study area is most likely to occur along the Weber River due to dam failure upstream (U. S. Bureau of Reclamation, 1983). It is unlikely that flooding due to earthquake events will affect either the burn plant or landfill sites.

### Slope Failure

Slope failures are common in the study area. The bluff in the northern portion of the study area is part of the South Weber landslide complex (Pashley and Wiggins, 1972). The Weber River has cut down and eroded laterally into the Weber River delta leaving a steep 200-foot-high bluff between the flood plain of the Weber River and the gently sloping delta surface upon which the study area is located. This steep bluff has been failing by a combination of rotational slump and earth flow landslides (Pashley and Wiggins, 1972). Figure 12 illustrates the landslide classification used in this report.

As the river cut down into the delta, the presence of silty clay beds in the lake deposits allowed the cut slopes to remain quite steep (Dames & Moore, 1985). As the river cut progressively deeper, the height of the banks exceeded the threshold of stability and landslides resulted (Dames & Moore, 1985). The landslides were, and are, progressive because 1) the landslide masses which accumulated at the toes of the slopes were carried away by the Weber River, hence any self-stabilizing effect of "buttressing" the toes of the slopes were removed, and 2) extensive perched ground water occurs within the sand layers within the soil sequence (Dames & Moore, 1985).

Most of the bluff in the northern portion of the study area is considered to be either landslide deposits or landslide headscarps (figure 4). Movement of one slide often creates oversteepened conditions around its headscarp which promotes additional movement of landslide movement in the scarp area. Earthquake ground shaking can accelerate the landslide process. Dames & Moore (1985) determined that a horizontal acceleration, due to a seismic event, of as little as 0.05g (5 percent of gravity) can induce significant movements of old landslide deposits along the bluffs above the Weber River. Earthquake-generated horizontal accelerations of 0.05g have an approximately 95 percent probability of occurring during a 100-year time period (Dames & Moore, 1985). Combined with the fact that topographic, soil strength, and ground-water conditions permit reactivation of parts of old landslide deposits without earthquake shaking, the likelihood of landsliding in the study area in the future is high. Miller (1980) has mapped one landslide deposit along the bluff just north of the landfill site. Examination of aerial photographs (1937, 1:20,000 scale; 1985, 1:24,000 scale) indicate that most of the landfill site is located on a possible slump. If this interpretation is correct, it is likely that this landslide is much older than the landslide mapped by Miller (1980), and that the likelihood of reactivation of the larger, older slump is lower.

Areas of existing landslides indicating a landslide hazard occur within the study area and are shown in figure 13. The burn plant is not in a landslide

hazard area. The landfill site is in a landslide hazard area and future refuse disposal cells should be kept away from the edge of the bluff where future landsliding is most likely to occur. It is likely that the possible slump which underlies most of the landfill site is old, possibly related to a seismic event which occurred just after Lake Bonneville dropped below the Provo level when the sediments were still saturated, and that the chance of further failure is low. Refuse has been used to fill the drainage in the northeast corner of section 3, T. 4 N., R. 1 W. (figure 14). EMCON Associates (1982) have recommended that a seismic slope stability study be completed for this fill. Because of the steep slopes of both the fill and natural slopes, the evidence for past instability of the surrounding natural slopes, and uncertainty concerning the techniques use to fill the drainage, it is agreed that such a study should be funded. The slope stability study should be completed for both static and earthquake ground shaking (dynamic) conditions and should take into consideration the liquefiable nature of the soils.

### Problem Soils

Potential problem soils include collapsible soils and soils with a high shrink-swell potential. Problems with soils can also occur due to differential settlement when construction occurs on sediments with different characteristics. Erickson and others (1968) mapped the soils in the Davis-Weber area, and soils in the study area have only low to moderate shrink-swell potential.

Although no problem soils have been identified in the study area, some may exist. Standard soil and foundation investigations should be conducted prior to development so that any problem soils may be identified and, if necessary, mitigative measures may be suggested.

### Shallow Ground Water and Ground-Water Contamination

A depth to shallow ground-water map has been produced for the study area as part of the liquefaction potential investigation (Anderson and others, 1982). This map shows that the depth to shallow ground water in the study area is generally greater than 45 feet. It is likely that perched ground water is also present above fine-grained lenses in some places the study area and that this is the case at the burn plant site. The spring in the eastern portion of the landfill site may be related to a shear zone along the eastern flank of the possible landslide.

In order to monitor possible leachate migration from the landfill, monitoring stations would be required along the bluff north of the landfill, as well as west and southwest of the landfill. Wells to monitor baseline water quality should be placed upgradient to the east and southeast of the landfill. Bonneville offshore sediments examined in exposures in other areas of the Weber delta are predominantly fine grained and, if this is also the case in the study area, it is unlikely that leachate could migrate downward through these sediments and contaminate deeper aquifers because of the low permeability of the offshore sediments and the artesian conditions of the deeper aquifers. It is therefore most important to place monitoring wells in the water-table aquifer which exists above these offshore sediments. It is expected that these sediments will be encountered in the subsurface at elevations between 4,700 feet and 4,800 feet. If the landfill site is an old landslide as suspected, these offshore sediments may be encountered at slightly lower elevations. Detailed logs of sediments encountered in the subsurface should be made for all wells so that perched

aquifers may be identified and monitored. Samples of the Bonneville offshore sediments should be collected during drilling and analyzed to verify their low permeability in the study area.

### Flooding

In the study area, floods are most likely to occur in response to cloudburst storms or rapid spring snowmelt and runoff, with the most serious flooding usually occurring along the Weber River. The primary cause of flooding along the Weber River is rapidly melting snow from late April to early July (Federal Emergency Management Agency, 1982). The largest snowmelt floods of record on the Weber River occurred in 1896, 1907, 1909, 1920, 1922, and 1952 (Federal Emergency Management Agency, 1982). Flooding due to cloudburst storms may occur along any of the smaller drainages in the study area.

### Recommendations

Geologic hazards affecting the study area have been identified in this report. The principle geologic hazard to the burn plant is earthquake ground shaking. Minimum requirements for earthquake-resistant design and construction are included in the UBC, but recent work indicates that these requirements may be inadequate for construction in unconsolidated materials in the area. Ground-shaking parameters used in the design of the burn plant were not reviewed for this study. Ground-shaking damage may be lessened by securing machines, shelves, and heavy furniture so that they cannot move and cause damage during seismic events.

The principle geologic hazard to the landfill is slope failure. Future refuse disposal cells should be placed away from the edge of the bluff. A site-specific slope-stability study for the refuse now filling the drainage should be conducted. This study should include the natural slopes immediately surrounding the drainage and should be conducted for both static and dynamic conditions. Possible liquefiable soils should be taken into consideration. This proposed slope stability study may provide information useful in evaluating setback distances from the edge of the bluff for future refuse cells.

As with any landfill, possible leachate migration is a major concern. Upgradient wells should be placed to the east and southeast of the landfill site. Monitoring wells should be placed to the north, west, and southwest of the landfill site. All water-table and perched aquifers above the Bonneville offshore deposits should be monitored. Detailed logs of the wells should be made so that monitoring depths may be determined. It would be advisable to monitor artesian aquifers as well as the perched and water-table aquifers. This may be possible using existing wells, such as Hill Field # 4 (figure 8) or any of the Layton City wells which are located in section 3, T. 4 N., R. 1 W., to the southwest of the landfill site.

### REFERENCES CITED

Algermission, S.T., and Steinbrugge, K.V., 1984, Seismic hazard and assessment: Some case studies: The Geneva Papers on Risk and Insurance, v. 9, no. 30, p. 8-26.

- Anderson, L.R., Keaton, J.F., Aubry, Kevin, and Ellis, S.J., 1982, Liquefaction potential map for Davis County, Utah: Department of Civil and Environmental Engineering, Utah State University State University, Logan, Utah, and Dames and Moore Consulting Engineers, Salt Lake City, Utah, 50 p.
- Arabasz, W.J., Smith, R.B., and Richins, W.D., editors, 1979, Earthquake studies in Utah, 1850-1978: University of Utah Seismograph Stations, Department of Geologic and Geophysics, 548 p.
- Borcherdt, T.D., Joyner, W.B., Warricke, R.E., and Gibbs, J.F., 1975, Response of local geologic units to ground shaking, in Borcherdt, R.D., ed., ed., Studies for seismic zonation of the San Francisco Bay region: U.S. Geological Survey Professional Paper 941-A, p. A52-A67.
- Clyde, C.G., Duffy, C.J., Fisk, E.P., Hoggan, D.H., and Hansen, D.E., 1984, Management of groundwater recharge areas in the mouth of Weber Canyon: Utah Water Research Laboratory Hydraulics and Hydrology Series UWLR/H-84/01, Utah State University, Logan, Utah, 100 p.
- Costa, J.E., and Baker, V.R., 1981, Surficial Geology; Building with the Earth: New York, John Wiley and Sons, 498 p.
- Currey, D.R., Atwood, Genevieve, and Mabey, D.R., 1984, Major levels of Great Salt Lake and Lake Bonneville: Utah Geological and Mineral Survey Map 73, 1:750,000 scale.
- Currey, D.R., and Oviatt, C.G., 1985, Durations, average rates, and probable causes of Lake Bonneville expansions, stillstands, and contractions during the last deep-lake cycle, 32,000 to 10,000 years ago, in Kay, P.A., and Diaz, H.F., eds., Problems of and prospects for predicting Great Salt Lake levels, Conference Proceedings, Center for Public Affairs and Administration: Salt Lake City, Utah, University of Utah, p. 9-24.
- Dames & Moore, 1985, Report, geotechnical and engineering geology investigation, project area for proposed sewer line south of St. Benedicts Hospital, Weber County, Utah, for city of Washington Terrace: Unpublished consultant's report, 11 p.
- Donovan, Neville, 1986, Ground motion issues for base isolation: National Science Foundation, Applied Technology Council, Proceedings of a Seminar and Workshop on Base Isolation and Passive Energy Dissipation, March 12-14, 1986, p. 343-353.
- Eardley, A.J., 1955, Tertiary history of north-central Utah, in Eardley, A.J., ed., Tertiary and Quaternary geology of the eastern Bonneville Basin: Utah Geological Society Guidebook to the Geology of Utah, no. 10, p. 37-44.
- Emcon Associates, 1982, Preliminary geotechnical investigation and waste management studies, NDRD disposal site, Davis County, Utah: Unpublished consultant's report, 36 p.
- Erickson, A.J., Wilson, LeMoyné, Hughie, V.K., Nielson, Woodrow, and Chadwick, R.S., 1968, Soil survey of Dais-Weber area, Utah: U.S. Department of Agriculture, Soil Conservation Service, in cooperation with Utah Agricultural Experiment Station, 149 p.

- Feth, J.H., Barker, D.A., Moore, L.G., Brown, R.J., and Veirs, C.E., 1966, Lake Bonneville: Geology and hydrology of the Weber Delta District, including Ogden, Utah. U.S. Geological Survey Professional Paper 518, 76 p.
- Hays, W.W., and King, K.W., 1982, Zoning of earthquake ground shaking hazard along the Wasatch fault zone, Utah: Seattle, Third International Earthquake Microzonation Conference, v. 3, p. 1307-1318.
- Kuribayashi, Eiichi, and Tatsuoka, Fumio, 1975, Brief review of liquefaction during earthquakes in Japan: Soils and Foundation, v. 15, no. 4, p. 81-92.
- 1977, History of earthquake-induced liquefaction in Japan: Japan Ministry of Construction, Public Works Research Institute Bulletin, v. 31, 26 p.
- Machette, M.N., Personius, S.F., Scott, W.E., and Nelson, A.R., 1986, Quaternary geology along the Wasatch Front: Evidence for ten fault segments and large-scale changes in slip rate along the Wasatch fault zone (expanded abstract): preliminary draft presented at 1986 USGS Earthquake Conference, Salt Lake City, Utah, 7 p.
- Miller, R.D., 1980, Surficial geologic map along part of the Wasatch Front, Salt Lake Valley, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1198, 1:100,000 scale.
- Oviatt, C.G., McCoy, W.D., Reider, R.G., 1985, Quaternary lacustrine stratigraphy along the lower Bear River, Utah; evidence for a shallow early Wisconsin lake in the Bonneville basin: Geological Society of America Abstracts with Programs, v. 17, no. 4, p. 260.
- Pashley, E.F., Jr., and Wiggins, R.A., 1972, Landslides of the northern Wasatch Front, in Hilpert, S.L., ed., Environmental Geology of the Wasatch Front, 1971: Utah Geological Association Publication 1, Salt Lake City, Utah, p. K1-K16.
- Reeve, John W., and Associates, 1962, Plan showing deep well locations in South Weber and North Davis Counties: Unpublished consultant's map, 1:24,000 scale.
- Robison, R.M., Christenson, G.E., Knight, R.U., Dewsnup, Wes, and Johnson, Mike, 1987, Earthquake and slope failure hazards, Utah County Comprehensive Hazard Mitigation Project, Utah, in McCalpin, James, ed., Proceedings of the 23rd Symposium on Engineering Geology and Soils Engineering: Utah State University, Logan, Utah, p. 499-521.
- Schwartz, D.P., and Coppersmith, K.J., 1984, Fault behavior and characteristic earthquakes: Examples from the Wasatch and San Andreas fault zones: Journal of Geophysical Research, v. 89, no. B7, p. 5681-5698.
- Scott, W.E., McCoy, W.D., Shroba, R.R., and Rubin, Meyer, 1983, Reinterpretation of the exposed record of the last two cycles of Lake Bonneville, western United States: Quaternary Research, v. 20, p. 261-285.

Stokes, W.L., 1977, Subdivisions of the major physiographic provinces in Utah: Utah Geology, v. 4, no. 1, p. 1-17.

U.S. Bureau of Reclamation, 1983, Technical report on dam failure inundation study, Echo Dam (Weber River Project, Utah): Unpublished report, 9 p.

Van Horn, Richard, 1975, Unevaluated reconnaissance geologic maps of Salt Lake and Davis Counties west of the Wasatch Front, Utah: Open-File Report 75-616, 1:48,000 scale.

#### GLOSSARY

- alluvial fan - A cone-shaped deposit of alluvium made by a stream where it runs out onto a level plain or meets a slower stream. The fans generally form where streams issue from mountains upon the lowland.
- alluvium - A general term for all detrital deposits resulting from the operations of modern rivers, thus including the sediments laid down in river beds, flood plains, lakes, fans at the foot of mountain slopes, and estuaries.
- aquifer - Stratum or zone below the surface of the earth capable of producing water as from a well.
- artesian - Refers to ground water under sufficient hydrostatic head to rise above the aquifer containing it.
- artesian aquifer - One that contains artesian water.
- colluvium - A general term applied to loose and incoherent deposits, usually at the foot of a slope or cliff, and brought there chiefly by gravity.
- confining bed - One which, because of its position and its impermeability or low permeability relative to that of the aquifer, gives the water in the aquifer artesian head.
- consolidation - Any or all of the processes whereby loose, soft, or liquid earth materials become firm and coherent.
- deltaic - Pertaining to, characteristic of, produced or deposited by, or derived from a delta. A delta is a landform created by deposition at a river/lake interface.
- Eolian - Term applied to the erosive action of the wind, and to deposits which are due to the transporting action of the wind.
- evapotranspiration - A term embracing that portion of the precipitation returned to the air through direct evaporation or by transpiration of vegetation, no attempt being made to distinguish between the two.

- fault - A fracture or fracture zone along which there has been displacement of the sides relative to one another parallel to the fracture.
- fluvial - Of, or pertaining to, rivers; produced by river action.
- glacial - Pertaining to, characteristic to, produced or deposited by, or derived from a glacier (a mass of moving ice).
- head - Pressure of a fluid upon a unit area due to the height at which the surface of the fluid stands above the point where the pressure is determined.
- Holocene - Geologic Time Unit, see Geologic Time Scale, Table 2.
- horst - a block of the earth's crust, generally long compared to its width, that has been uplifted along faults relative to the rocks on either side.
- interlacustrine - That period of time between lake cycles when a lake is at its lowest stand.
- lacustrine - Pertaining to, produced by, or formed in a lake or lakes.
- lake cycle - That period of time during which a lake rises from a interlacustrine low stand to its highest stand, and that period of time during which the lake recedes to the next interlacustrine low stand.
- lenticular - Shaped approximately like a double convex lens.
- liquefaction - A process by which certain water saturated soils lose bearing strength due to ground shaking as support is transferred from grain to grain contact to intergranular water as pore pressures increase.
- magnitude - (of an earthquake) A quantity characteristic of the total energy released by an earthquake as contrasted to "intensity" which describes its effects at a particular place.
- normal fault - A fault at which the hanging wall has been depressed, relative to the footwall.
- Paleozoic - Geologic time unit, see Geologic Time Scale, Table 2.
- perched aquifer - An aquifer in which ground water is separated from an underlying body of ground water by unsaturated rock.
- permeability - The permeability (or perviousness) of rock is its capacity for transmitting a fluid. Degree of permeability depends upon the size and shape of the pores, the size and shape of their interconnections, and the extent of the latter.

- permeable - Pervious. Having a texture that permits water to move through it perceptibly under the head differences ordinarily found in subsurface water.
- Pleistocene - Geologic time unit, see Geologic Time Scale, Table 2.
- Precambrian - Geologic time unit, see Geologic Time Scale, Table 2.
- Quaternary - Geologic time unit, see Geologic Time Scale, Table 2.
- saturated - A rock or soil is saturated with respect to water if all its interstices are filled with water.
- seismic - Pertaining to an earthquake or earth vibration, including those that are artificially induced.
- sorting - In a descriptive sense, the term may be used to indicate the degree of similarity, in respect to some particular characteristic (such as particle size), of the component parts in a mass of material. A sediment is well sorted when most of the particles which make up the deposit are about the same size.
- stratified - Formed or lying beds, layers, or strata.
- stratum - A section of the formation that consists throughout of approximately the same kind of rock material; a stratum may consist of an indefinite number of beds, and a bed may consist of numberless layers; the distinction of layer and bed is not always obvious.
- surficial - Characteristic of, pertaining to, formed on, situated at, or occurring on the earth's surface; especially, consisting of unconsolidated residual, alluvial, or glacial deposits lying on the bedrock.
- tectonic - Of or related to deformation of the earth's crust.
- Tertiary Period - Geologic time unit, see Geologic Time Scale, Table 2.
- water table - The upper surface of a zone of saturation except where that surface is formed by an impermeable body.

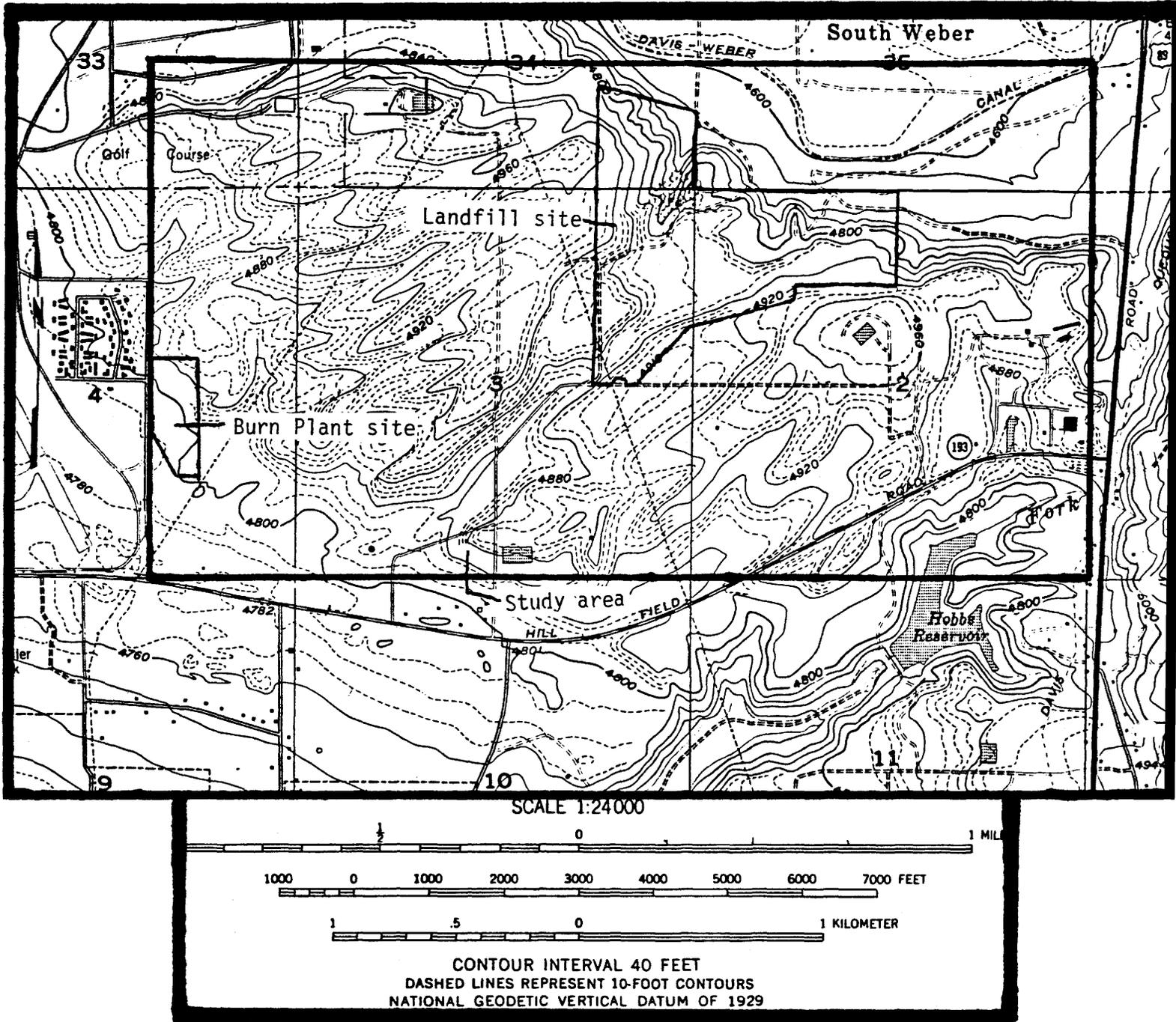
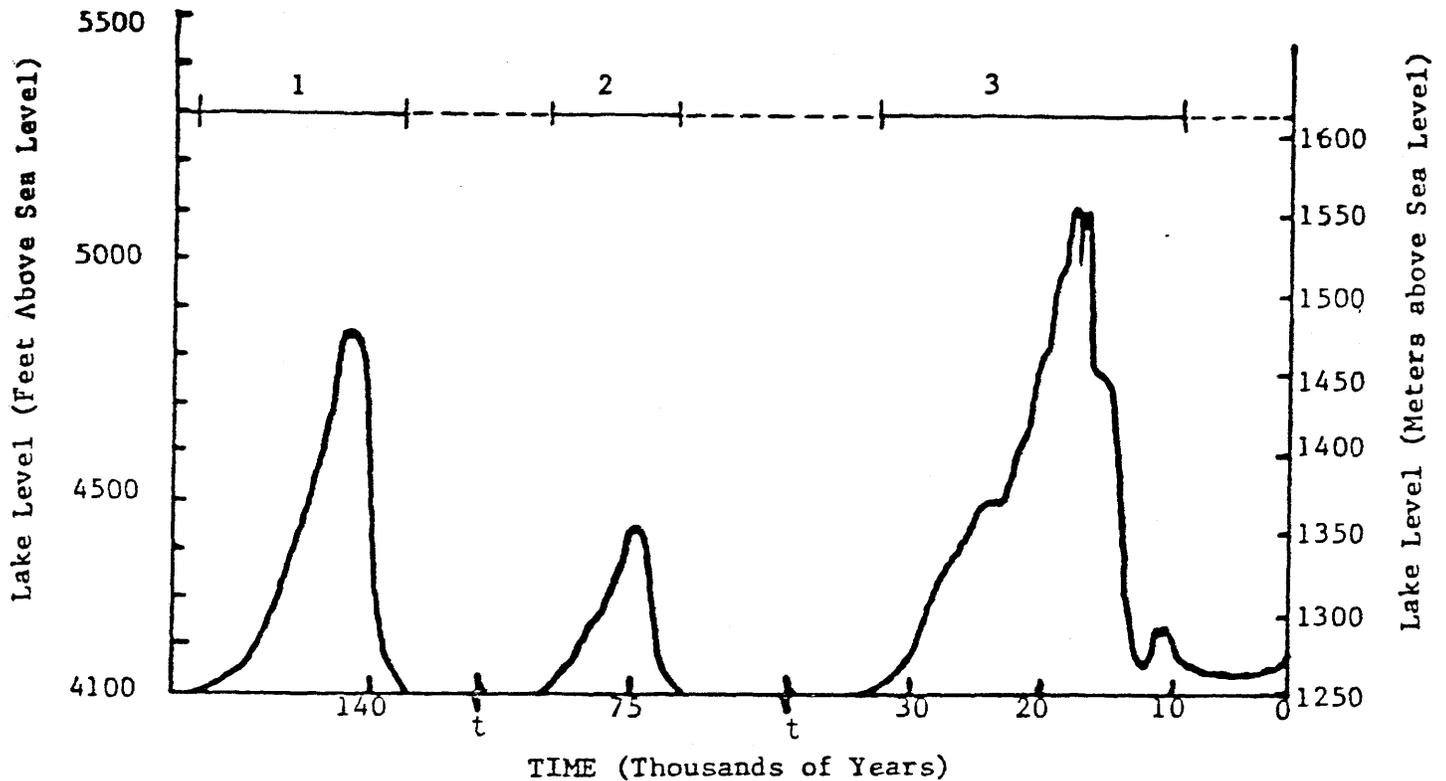


Figure 1. Location map for NDRD site study area, northern Davis County, Utah.



Explanation

- 1 - Little Valley lake cycle.
- 2 - Cutler Dam lake cycle.
- 3 - Bonneville lake cycle.
- t - Splice point on graph. Periods of time during interlacustrine phases have been removed to condense graph.

Figure 2. Schematic diagram showing a hydrograph of probable lake levels in the Lake Bonneville basin for the past 150,000 years. Numbered solid lines above lake level curves represent time periods of lake cycles described in this report. Dashed lines represent interlacustrine periods when lakes in the Lake Bonneville basin stood at relatively low levels or were nonexistent. (Hydrograph modified from Currey and Oviatt, 1985, and extended past 35,000 years before present by Machette and others, 1986, on the basis of recent stratigraphic studies of pre-Lake Bonneville deposits, with additional modifications for this report).

- 1- Bonneville lake cycle transgressive phase.
- 2- Bonneville lake cycle regressive phase.
- 3- Stansbury deposits.
- 4- Bonneville deposits.
- 5- Provo deposits.
- 6- Gilbert deposits.
- 7- Stansbury Shoreline stage.
- 8- Bonneville Shoreline stage.
- 9- Provo Shoreline stage.
- 10- Gilbert Shoreline stage.

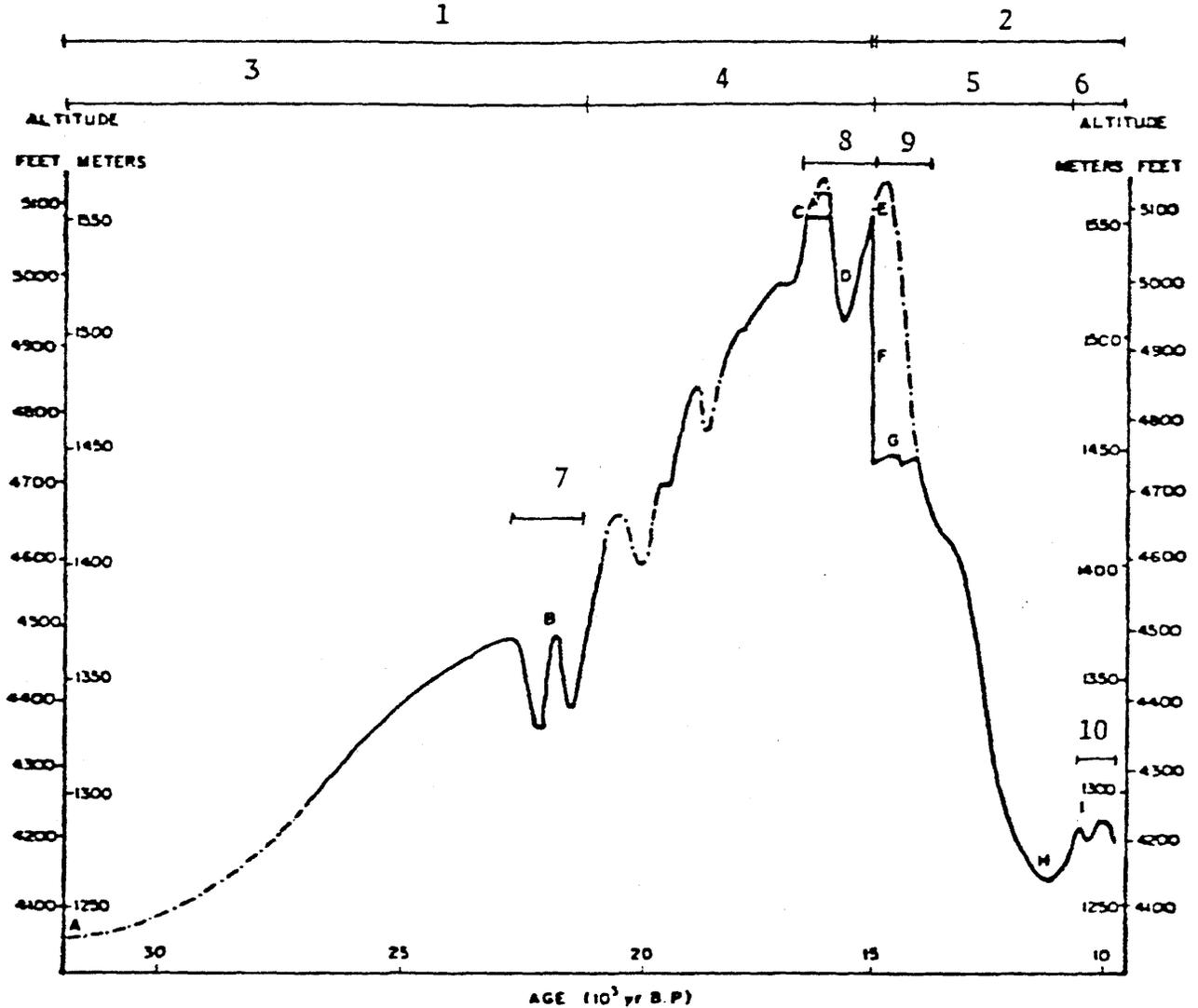
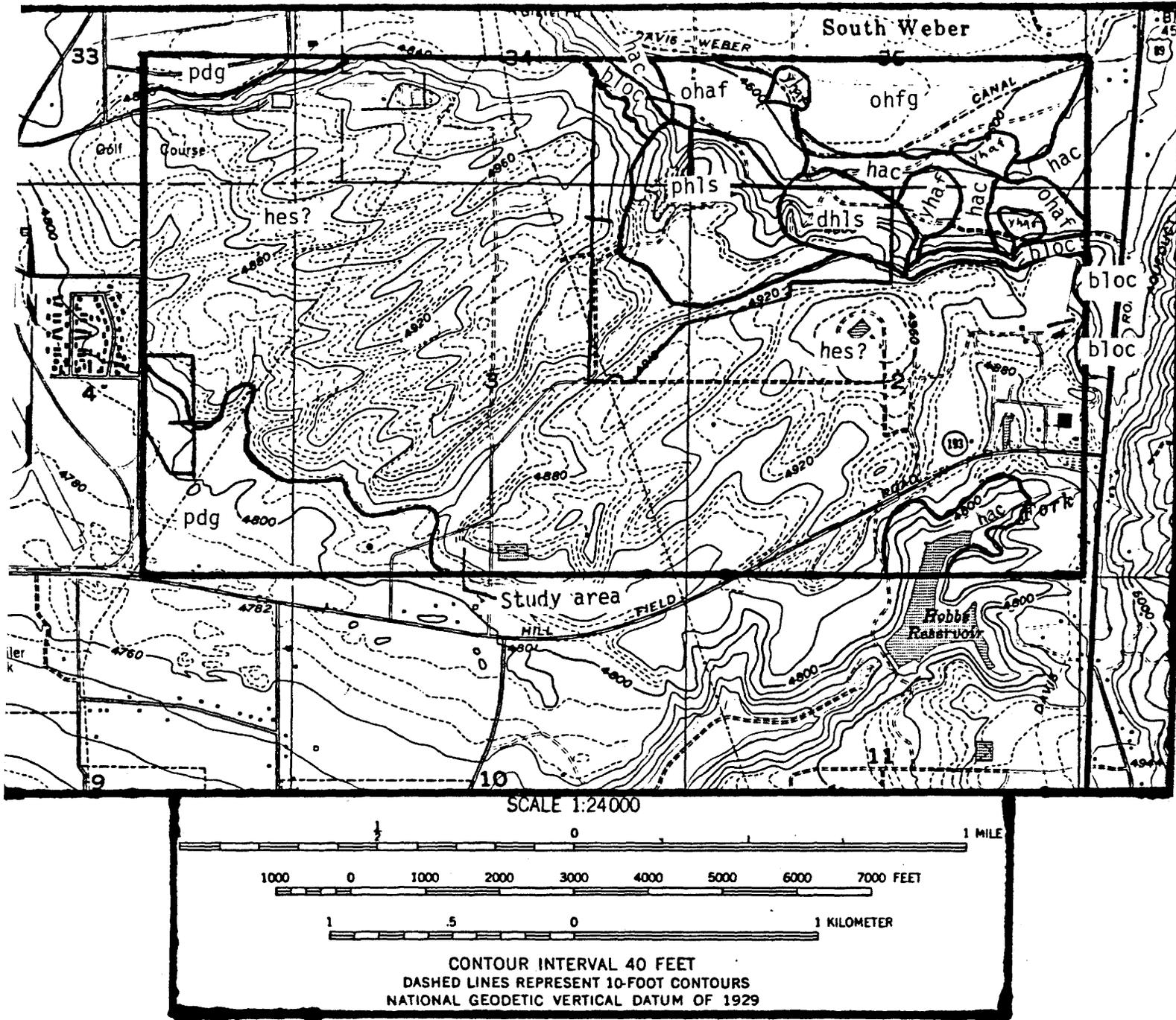


Figure 3. Hydrograph of Lake Bonneville (adapted from Currey and Oviatt, 1985). Numbers show time periods of terminology, and letters show time and altitude of events discussed in this report.



EXPLANATION

All map units are of Quaternary age.

- bloc - Bonneville lacustrine offshore silt and clay.
- pdg - Provo deltaic sand and gravel.
- ohfg - Older Holocene fluvial sand and gravel.
- hac - Thin post-Lake Bonneville alluvial-fan, colluvial, and landslide deposits over older Holocene fluvial sand and gravel.
- ohaf - Older Holocene alluvial-fan deposits.
- yhaf - Younger Holocene alluvial-fan deposits.
- hes? - Post-Lake Bonneville ? eolian ? sand.
- dhls - Definite post-Lake Bonneville landslide.
- phls - Possible post-Lake Bonneville landslide.

Figure 4. Surficial geologic map of NDRD site study area, northern Davis County, Utah.

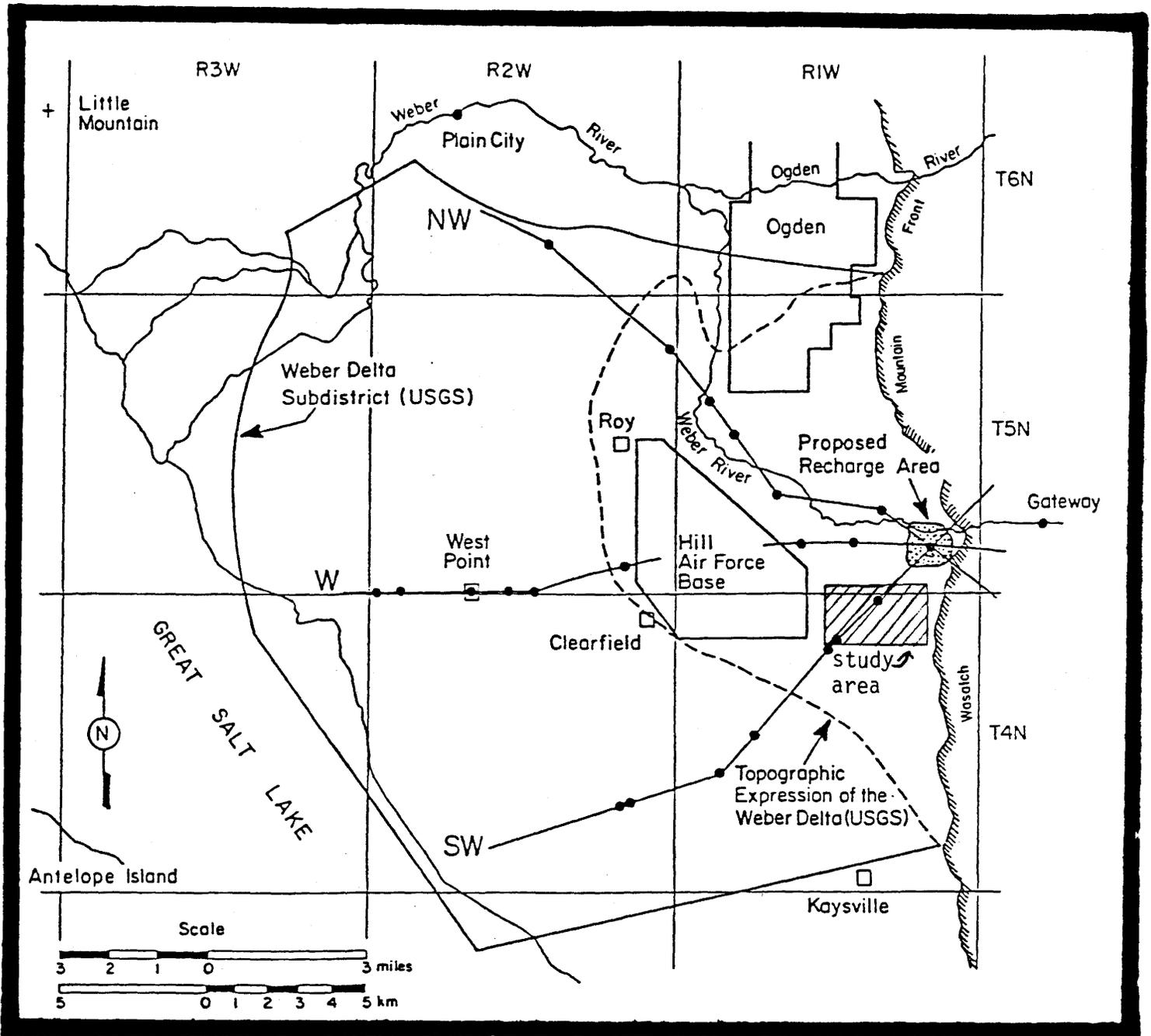


Figure 5. Location of geologic cross sections through southern Weber and northern Davis Counties, Utah (adapted from Clyde and others, 1984). Cross section SW is shown in figure 6.

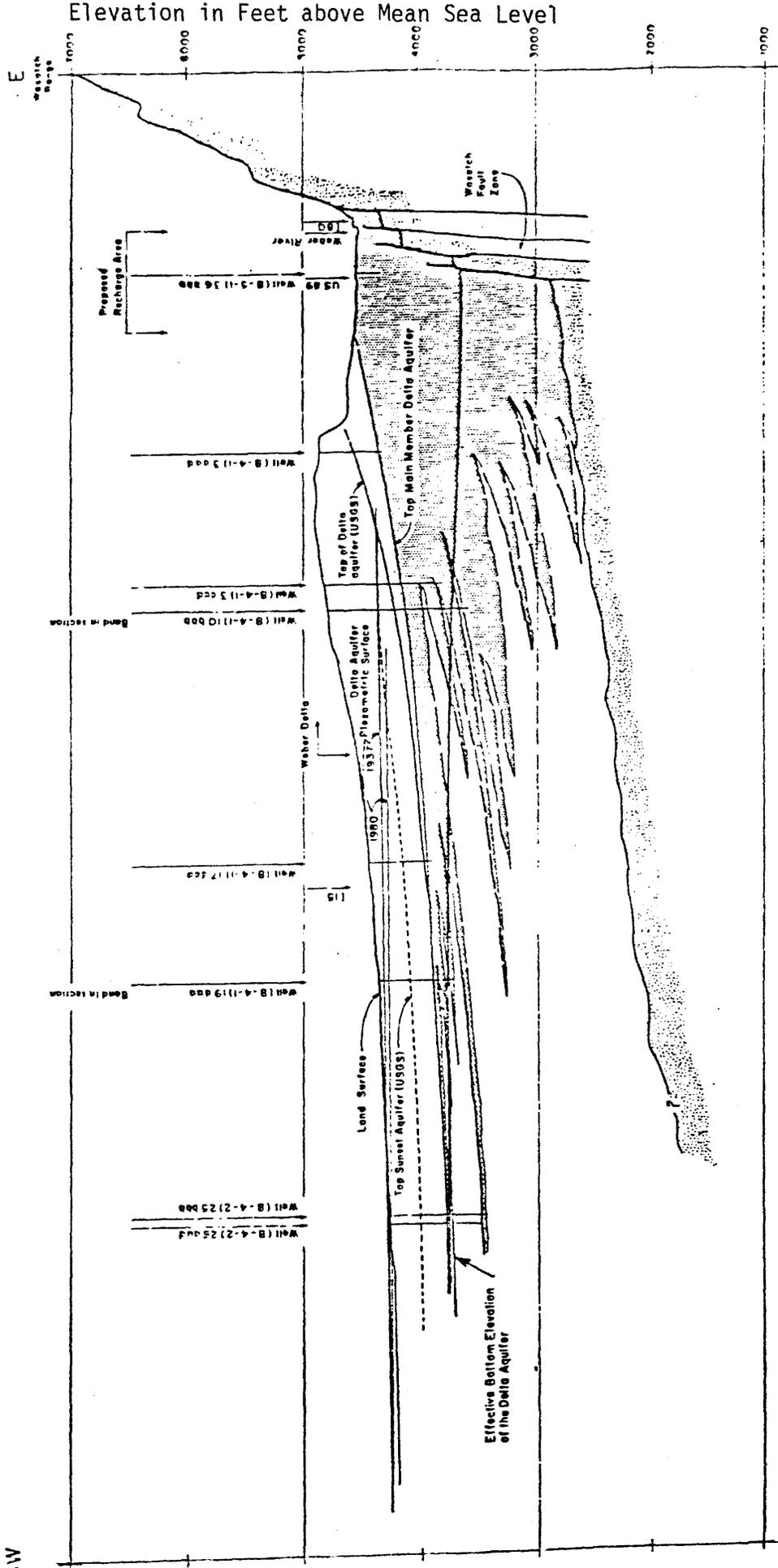
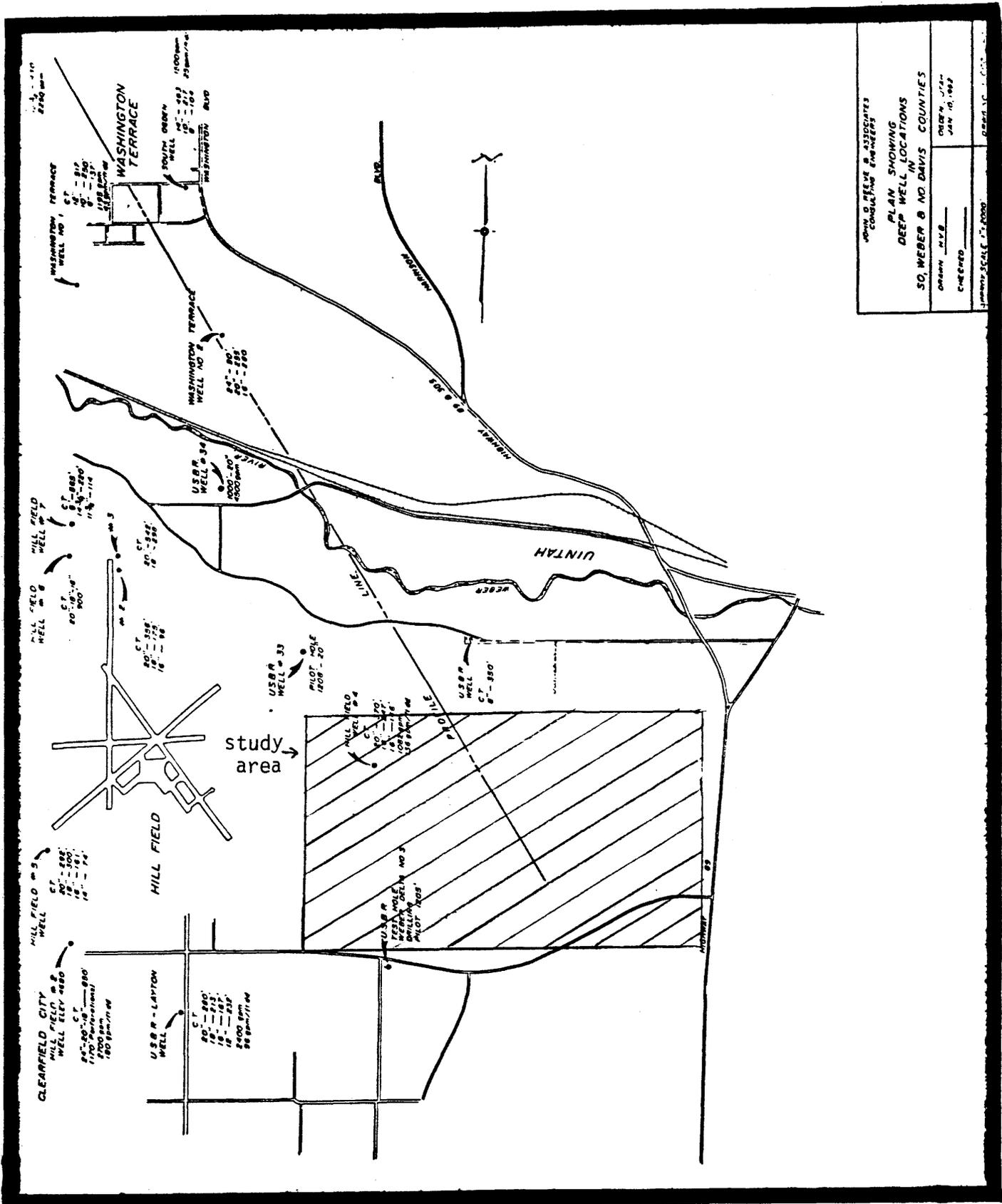


Figure 6. Geologic cross section SW showing location of aquifers in the study area (Clyde and others, 1984). Location shown on figure 5.





JOHN O. REEVE & ASSOCIATES CONSULTING ENGINEERS	
PLAN SHOWING DEEP WELL LOCATIONS SO. WEBER & MO. DAVIS COUNTIES	
DRAWN BY M.E.B.	CHECKED BY J.W.M.
DATE JAN. 10, 1962	
PROJECT NO. 10000	

Figure 8. Map showing location of topographic profile and water wells shown in figure 9 (John O. Reeve and Associates Consulting Engineers, 1962). Approximately 1:54,000 scale.

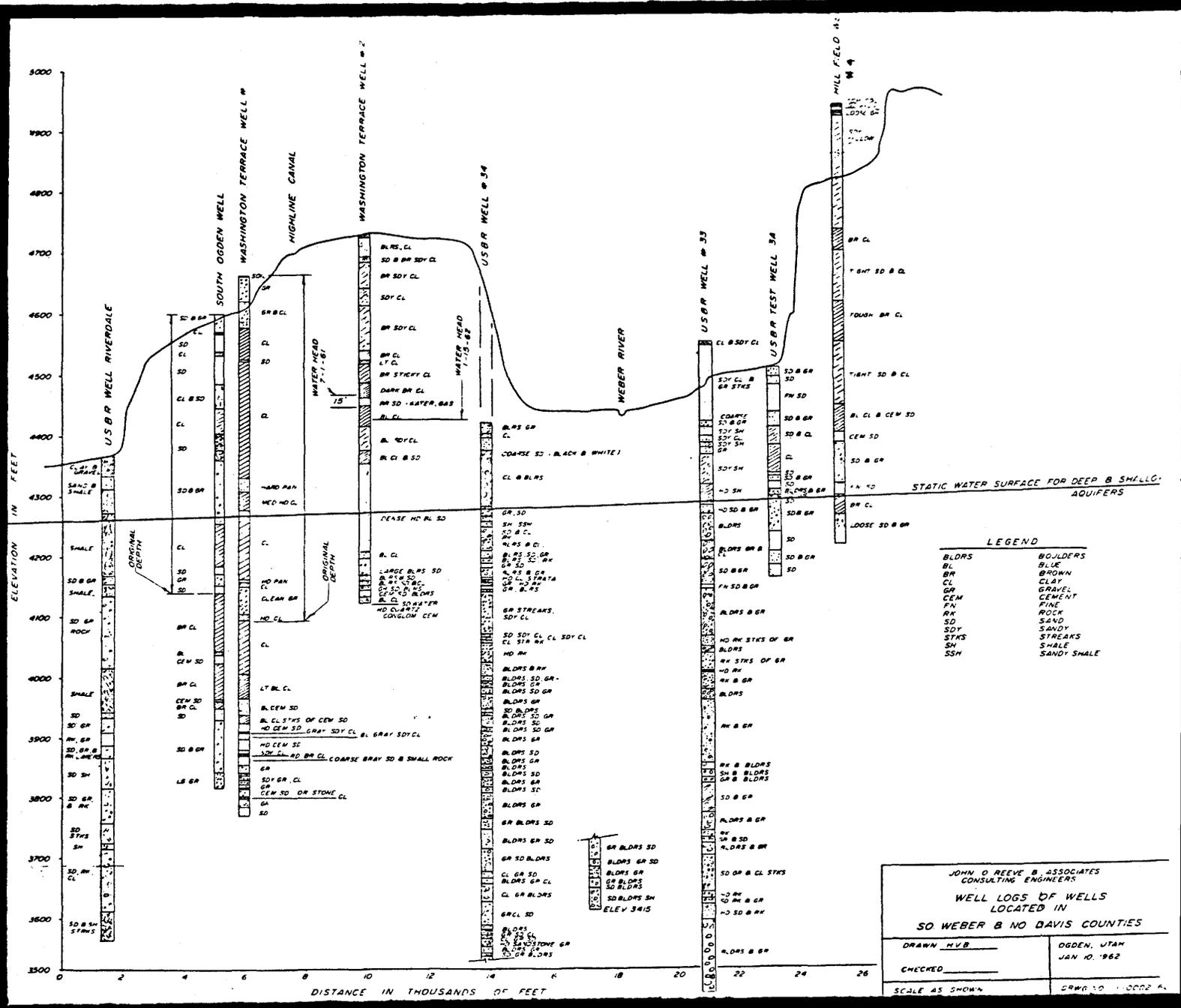


Figure 9. Topographic profile with water-well data showing subsurface geology (John O. Reeve and Associates Consulting Engineers, 1962). Location of profile is shown in figure 8.

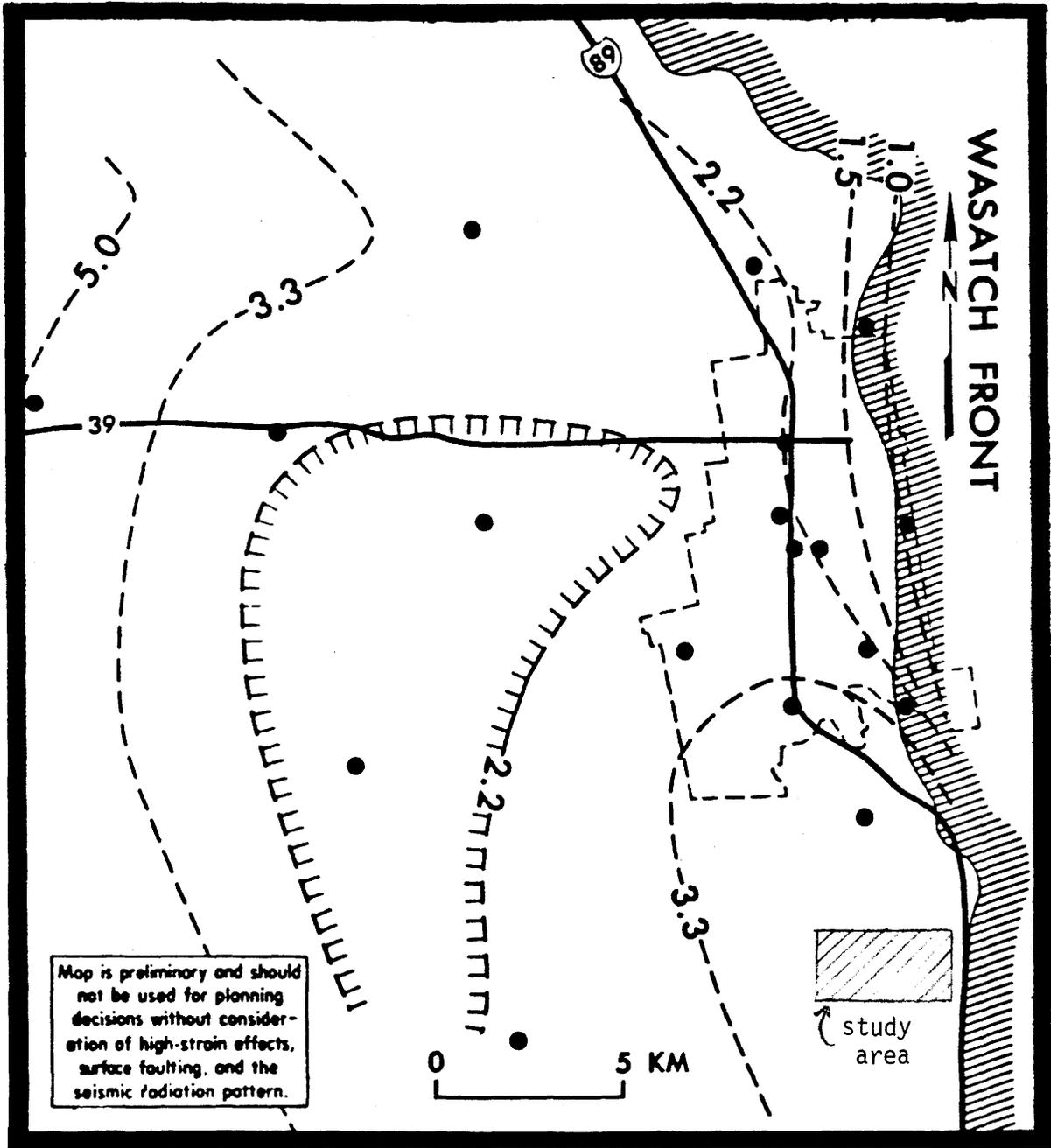


Figure 10. Map of estimated horizontal ground response for the period band 0.2-0.7 seconds, Ogden area (Hays and King, 1982). Values on contours indicate ratio of values of velocity response spectra which would be expected relative to bedrock. These values provide an estimate of the relative response of 3-7 story buildings subjected to ground shaking. Hachures denote the area of low ground response. Corporate limits of Ogden are shown as dashes.

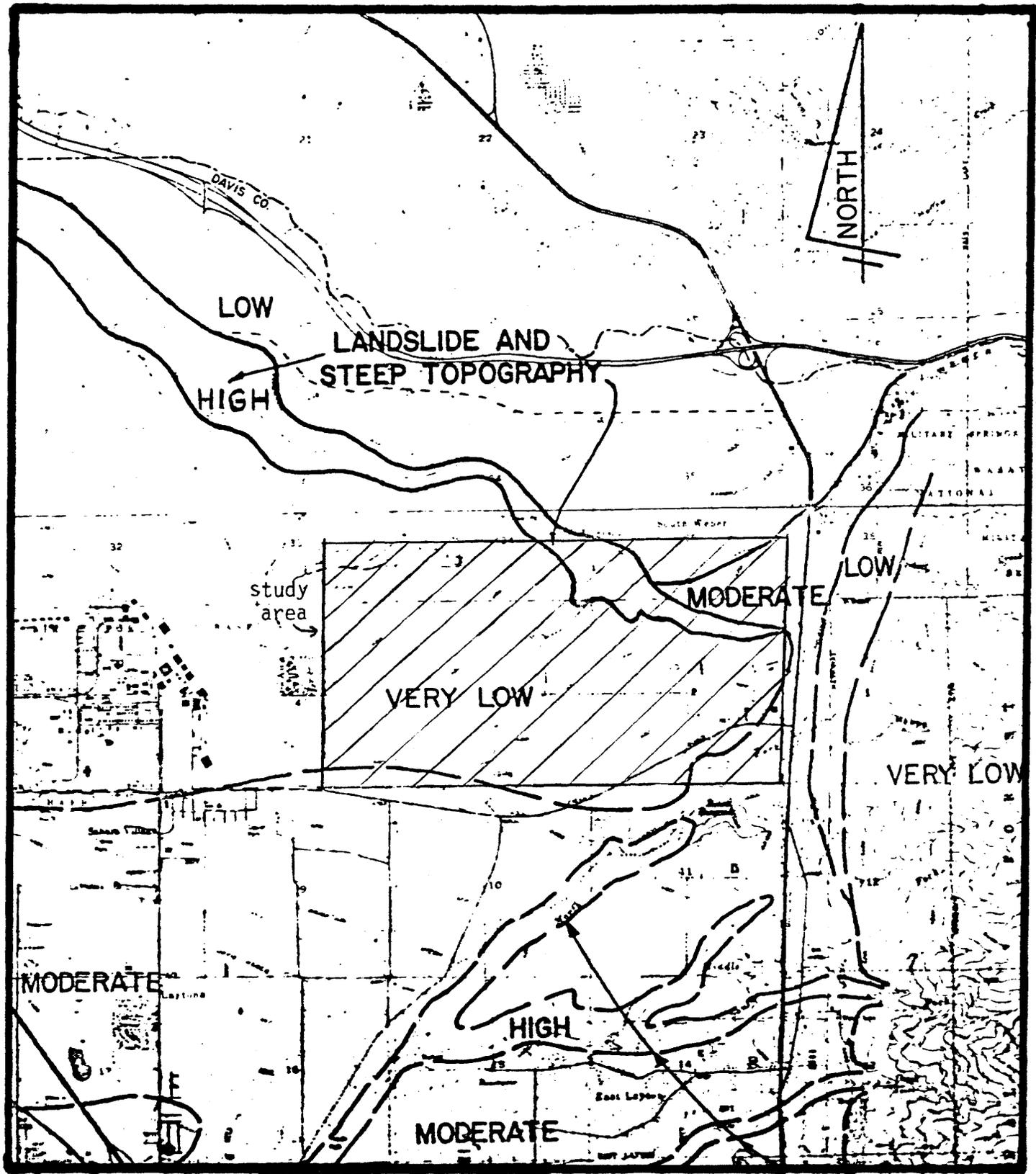
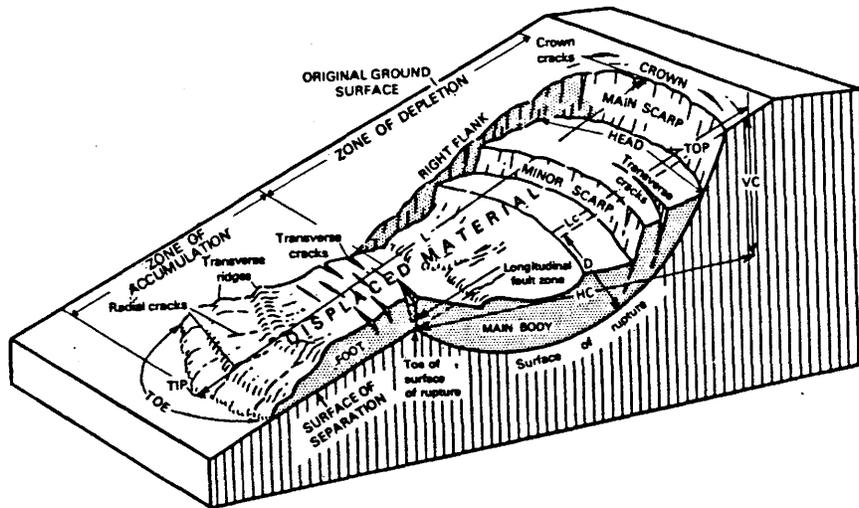


Figure 11. Liquefaction Potential Map for a portion of northern Davis County, Utah (adapted from Anderson and others, 1982). 1:48,000 scale.

TYPE OF MOVEMENT		TYPE OF MATERIAL			
		BEDROCK	ENGINEERING SOILS		
			Predominantly coarse	Predominantly fine	
FALLS		Rock fall	Debris fall	Earth fall	
TOPPLES		Rock topple	Debris topple	Earth topple	
SLIDES	ROTATIONAL	FEW UNITS	Rock slump	Debris slump	Earth slump
	TRANSLATIONAL		Rock block slide	Debris block slide	Earth block slide
			MANY UNITS	Rock slide	Debris slide
LATERAL SPREADS		Rock spread	Debris spread	Earth spread	
FLOWS		Rock flow (deep creep)	Debris flow (soil creep)	Earth flow	
COMPLEX		Combination of two or more principal types of movement			



Slump and earth flow

Figure 12. Landslide classification and terminology (Varnes, 1978).

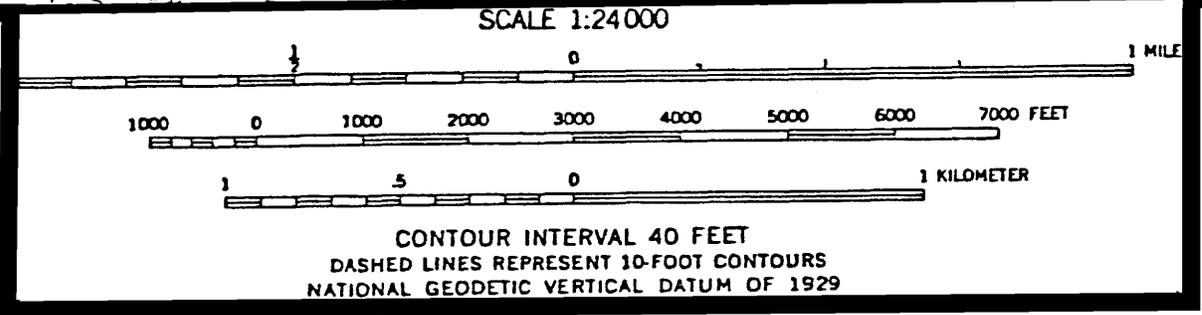
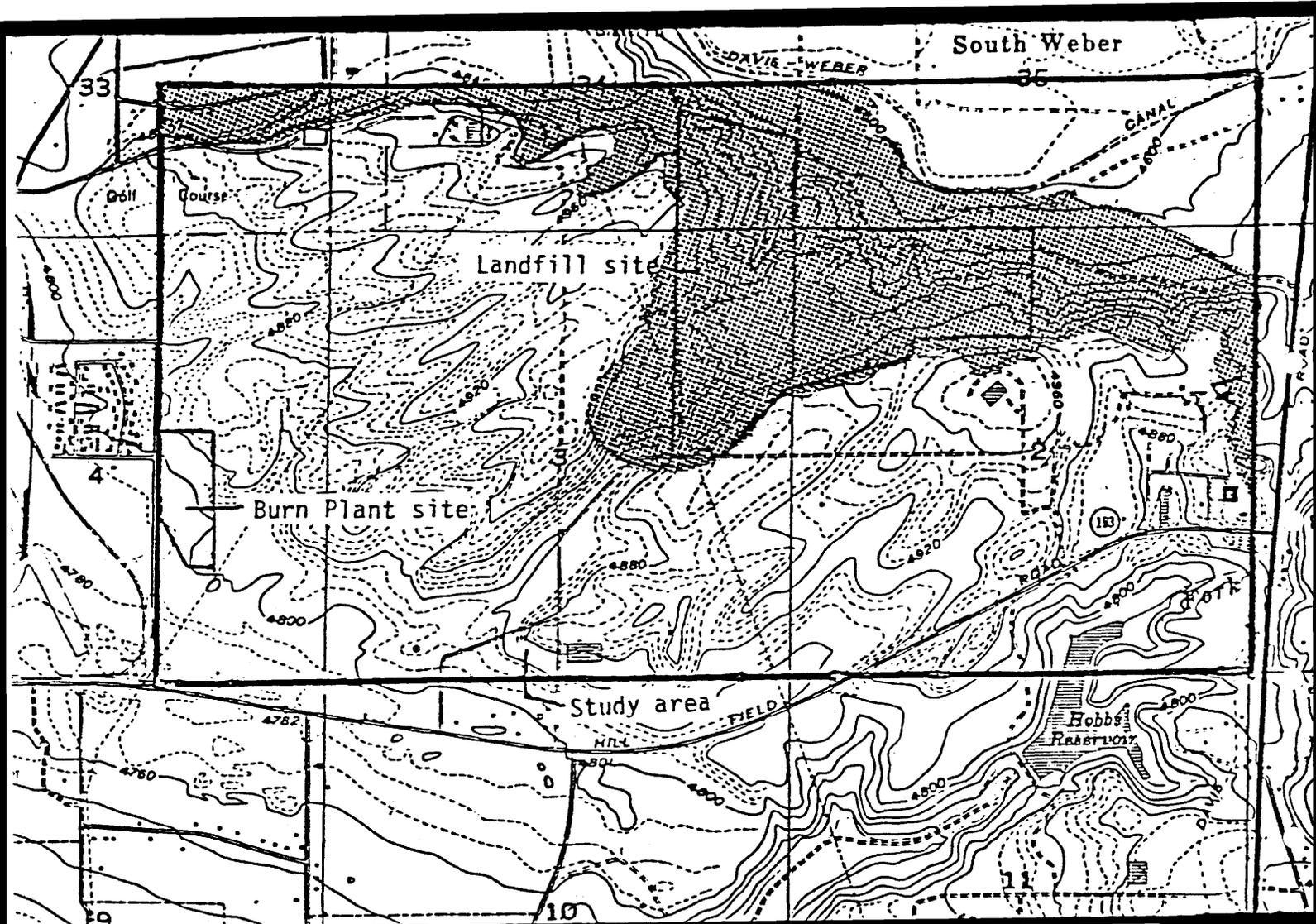


Figure 13. Areas of landslide hazard (stipled) in the NDRD site study area.

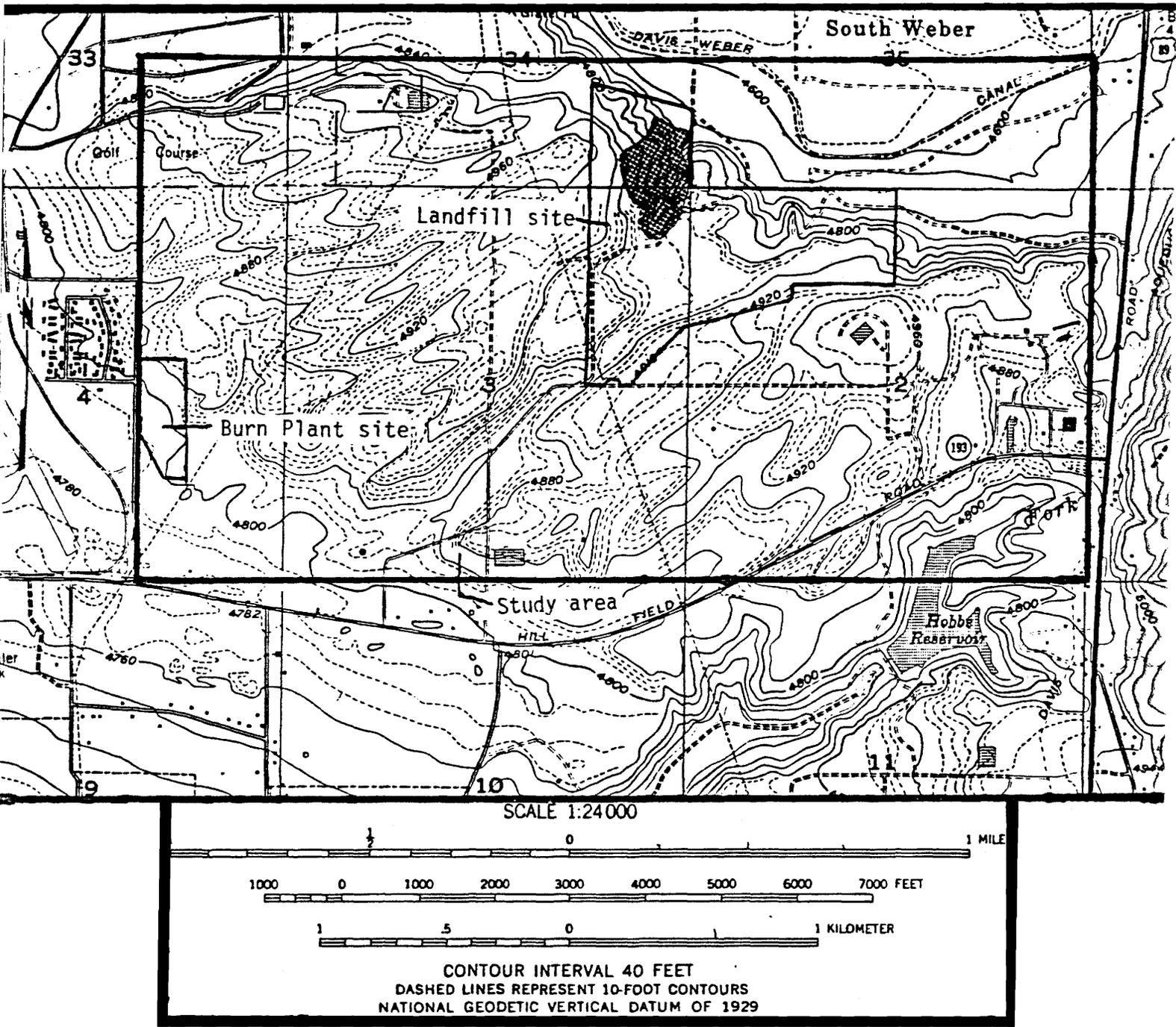


Figure 14. Recommended study area for stability of refuse fill, NDRD site study area, northern Davis County, Utah.

**MODIFIED MERCALLI INTENSITY SCALE OF 1931  
(Abridged)**

- I. Not felt except by a very few under especially favorable circumstances.
- II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
- III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.
- IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls made cracking sound. Sensation like heavy truck striking building; standing motor cars rocked noticeably.
- V. Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop.
- VI. Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.
- VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.
- VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Disturbed persons driving motor cars.
- IX. Damage considerable in specially designed structures; well designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.
- X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (stopped) over banks.
- XI. Few, if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
- XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

Table 1. Modified Mercalli intensity scale of 1931 (abridged)  
(Earthquake Information Bulletin, 1974).



# DECADE OF NORTH AMERICAN GEOLOGY 1983 GEOLOGIC TIME SCALE



GEOLOGICAL SOCIETY OF AMERICA

Table 2. Geologic time scale used for this report.

CENOZOIC					MESOZOIC					PALEOZOIC					PRECAMBRIAN																																																				
AGE (Ma)	MAGNETIC POLARITY	PERIOD	EPOCH	AGE	PICKS (Ma)	AGE (Ma)	MAGNETIC POLARITY	PERIOD	EPOCH	AGE	PICKS (Ma)	UNCERT. (Ma)	AGE (Ma)	PERIOD	EPOCH	AGE	PICKS (Ma)	UNCERT. (Ma)	AGE (Ma)	EDM	ERA	BOV AGES (Ma)																																													
0.01		QUATERNARY	PLISTOCENE	CALABRIAN	0.01	66.4		CRETACEOUS	LATE	MAASTRICHTIAN	66.4		245	PERMIAN	LATE	YATARIAN	245	20	PROTEROZOIC	LATE		170																																													
1.8		PLIOCENE	PIACENZIAN	1.8	74.8	4	CAMPANIAN		74.8	4	EARLY	KAZANIAN	253		20	KUNGURIAN	258	24					ARTINSKIAN	263	22	SAKMARIAN	268	12	ASSELIAN	288	12																																				
3.4			ZANCLEAN	3.4	84.0	4.5	CENOMANIAN		84.0	4.5		LATE	GZELIAN		288		12	MOSCOWIAN						298	10		BASHKIRIAN	318		20	SERPUKHOVIAN	320	20	VISEAN	333	22																															
6.3			MESSINIAN	6.3	87.5	2.5			ALBIAN	87.5	2.5		EARLY		MIDDLE	TOURNAISIAN	352						8	FAMMENIAN	360	10		FRASNIAN	367	12		GIVETIAN	374		10	EIFELIAN	380	10	EMSIAN	387	20																										
8.8		NEOGENE	TORTONIAN	8.8	113	4	NEOCOMIAN			113	4	LATE		EARLY			SIEGENIAN	394					22		GEDINNIAN	401	10		PRIDOLIAN	408	12		LUDLOVIAN	414	12		WENLOCKIAN	421		12	LLANDOVERIAN	428	8	ASHGILLIAN	438	12	CARADOCIAN	448	12	LLANDEILAN	458	16	LLANVIRNIAN	468	16	ARENIGIAN	478	16	TREMADOCIAN	488	20	TREMPEALEUAN	508	22	FRANCONIAN	523	16
11.2			SERRAVALLIAN	11.2	119	0			EARLY	119	0		MIDDLE		LATE	EARLY		ORDOVICIAN					LATE	TITHONIAN		144	5	KIMMERIDGIAN		152	12	OXFORDIAN		156	8	CALLOVIAN		163	15	BATHONIAN		169	15		BAJOCIAN	176		34	AALENIAN		183	34		TOARCIAN	187		34	PLIENSCHACHIAN		193	28		SINEMURIAN	198		32	HETTANGIAN
16.8			LANGHIAN	16.8	124	0	VALANGINIAN			124	0	EARLY		MIDDLE			LATE								EARLY	LATE	TITHONIAN		144	5	KIMMERIDGIAN		152	12	OXFORDIAN		156	8	CALLOVIAN		163	15	BATHONIAN	169		15	BAJOCIAN	176		34	AALENIAN	183	34		TOARCIAN	187	34		PLIENSCHACHIAN	193	28	SINEMURIAN		198	32	HETTANGIAN	
21.8		BURDIGALIAN	21.8	124	0	BERRIASIAN			124	0	LATE		EARLY		MIDDLE	LATE		EARLY					TITHONIAN	144				5	KIMMERIDGIAN	152		12	OXFORDIAN	156		8	CALLOVIAN	163		15	BATHONIAN	169		15	BAJOCIAN	176		34	AALENIAN	183		34	TOARCIAN	187		34	PLIENSCHACHIAN	193		28	SINEMURIAN		198	32	HETTANGIAN		204
23.7		AQUITANIAN	23.7	124	0		TITHONIAN		124	0		LATE		EARLY			MIDDLE							LATE	EARLY	TITHONIAN	144	5		KIMMERIDGIAN	152	12		OXFORDIAN	156	8		CALLOVIAN	163	15		BATHONIAN	169	15		BAJOCIAN	176	34		AALENIAN	183	34		TOARCIAN	187	34		PLIENSCHACHIAN	193	28		SINEMURIAN	198	32		HETTANGIAN	204
31.8		OLIGOCENE	CHATTEAN	31.8	131	0			VALANGINIAN	131	0		LATE		EARLY	MIDDLE		LATE					EARLY				TITHONIAN	144	5		KIMMERIDGIAN	152	12		OXFORDIAN	156	8		CALLOVIAN	163	15		BATHONIAN	169	15		BAJOCIAN	176	34		AALENIAN	183	34		TOARCIAN	187	34		PLIENSCHACHIAN	193	28		SINEMURIAN	198	32		HETTANGIAN
33.7			RUPELIAN	33.7	131	0	BERRIASIAN			131	0	LATE		EARLY			MIDDLE		LATE	EARLY	TITHONIAN	144		5	KIMMERIDGIAN	152		12	OXFORDIAN	156		8	CALLOVIAN	163		15	BATHONIAN	169		15	BAJOCIAN	176		34	AALENIAN	183		34	TOARCIAN	187		34	PLIENSCHACHIAN	193		28	SINEMURIAN	198		32	HETTANGIAN	204		19	NORIAN	208	
36.0		PALEOGENE	PRIABONIAN	36.0	144	5			TITHONIAN	144	5		LATE		EARLY	MIDDLE		LATE				EARLY	TITHONIAN	144		5	KIMMERIDGIAN	152		12	OXFORDIAN	156		8	CALLOVIAN	163		15	BATHONIAN	169		15	BAJOCIAN	176		34	AALENIAN	183		34	TOARCIAN	187		34	PLIENSCHACHIAN	193		28	SINEMURIAN	198		32	HETTANGIAN	204		19	NORIAN
40.0			BARTONIAN	40.0	144	5	KIMMERIDGIAN			144	5	LATE		EARLY			MIDDLE		LATE	EARLY	TITHONIAN			144	5	KIMMERIDGIAN		152	12	OXFORDIAN		156	8	CALLOVIAN		163	15	BATHONIAN		169	15	BAJOCIAN		176	34	AALENIAN		183	34	TOARCIAN		187	34	PLIENSCHACHIAN		193	28	SINEMURIAN		198	32	HETTANGIAN		204	19	NORIAN	
43.8		Eocene	LUTETIAN	43.8	152	12			KIMMERIDGIAN	152	12		LATE		EARLY	MIDDLE		LATE				EARLY	TITHONIAN	144	5		KIMMERIDGIAN	152	12		OXFORDIAN	156	8		CALLOVIAN	163	15		BATHONIAN	169	15		BAJOCIAN	176	34		AALENIAN	183	34		TOARCIAN	187	34		PLIENSCHACHIAN	193	28		SINEMURIAN	198	32		HETTANGIAN	204	19		NORIAN
48.0			Ypresian	48.0	156	8	OXFORDIAN	156		8	LATE	EARLY		MIDDLE			LATE		EARLY	TITHONIAN	144			5	KIMMERIDGIAN	152		12	OXFORDIAN	156		8	CALLOVIAN	163		15	BATHONIAN	169		15	BAJOCIAN	176		34	AALENIAN	183		34	TOARCIAN	187		34	PLIENSCHACHIAN	193		28	SINEMURIAN	198		32	HETTANGIAN	204		19	NORIAN	208	
57.0		Paleocene	THANETIAN	57.0	163	15		CALLOVIAN	163	15			LATE		EARLY	MIDDLE		LATE			EARLY	TITHONIAN	144	5		KIMMERIDGIAN	152	12		OXFORDIAN	156	8		CALLOVIAN	163	15		BATHONIAN	169	15		BAJOCIAN	176	34		AALENIAN	183	34		TOARCIAN	187	34		PLIENSCHACHIAN	193	28		SINEMURIAN	198	32		HETTANGIAN	204	19		NORIAN	208
60.6			UNNAMED	60.6	169	15	BATHONIAN		169	15	LATE	EARLY		MIDDLE			LATE		EARLY	TITHONIAN			144	5	KIMMERIDGIAN		152	12	OXFORDIAN		156	8	CALLOVIAN		163	15	BATHONIAN		169	15	BAJOCIAN		176	34	AALENIAN		183	34	TOARCIAN		187	34	PLIENSCHACHIAN		193	28	SINEMURIAN		198	32	HETTANGIAN		204	19	NORIAN		208
63.0		DANIAN	63.0	176	34	BAJOCIAN		176	34	LATE			EARLY		MIDDLE	LATE		EARLY			TITHONIAN	144	5	KIMMERIDGIAN		152	12	OXFORDIAN		156	8	CALLOVIAN		163	15	BATHONIAN		169	15	BAJOCIAN		176	34	AALENIAN		183	34	TOARCIAN		187	34	PLIENSCHACHIAN		193	28	SINEMURIAN		198	32	HETTANGIAN		204	19	NORIAN		208	18
66.4			66.4	183	34		AALENIAN	183	34		LATE	EARLY		MIDDLE			LATE		EARLY	TITHONIAN		144	5		KIMMERIDGIAN	152	12		OXFORDIAN	156	8		CALLOVIAN	163	15		BATHONIAN	169	15		BAJOCIAN	176	34		AALENIAN	183	34		TOARCIAN	187	34		PLIENSCHACHIAN	193	28		SINEMURIAN	198	32		HETTANGIAN	204	19		NORIAN	208	18

<b>Project:</b> Preliminary geologic hazard investigation for two proposed water storage reservoir sites, Clearfield City, Utah			<b>Requesting Agency:</b> Clearfield City Engineering and Inspections
<b>By:</b> Mike Lowe	<b>Date:</b> 3-14-88	<b>County:</b> Davis	<b>Job No.:</b> D10
<b>USGS Quadrangle:</b> Clearfield and Kaysville			

### INTRODUCTION

At the request of Jackie E. Bippes, Director of Clearfield City Engineering and Inspection, preliminary geologic hazard investigations of two potential sites for a two-million gallon buried concrete water storage reservoir were performed. The Park Site is located in the SW 1/4 SW 1/4 sec. 36, T. 5 N., R. 2 W., at an approximate elevation of 4,535 feet in northern Clearfield City (attachment 1). The HAFB Site is located in the SE 1/3 SW 1/4 sec. 31, T. 5 N., R. 1 W., at an approximate elevation of 4,760 feet on the southwestern portion of Hill Air Force Base (attachment 1). The purpose of the investigation was to identify any geologic hazards affecting the sites. The scope of work for this investigation included a literature search and an examination of aerial photographs (1985, approximately 1:24,000 scale). This report was reviewed by Gary E. Christenson of the Utah Geological and Mineral Survey.

### General Geology

The Park Site is located just west of the western edge of the Weber River delta, which forms the hill that rises east of the site, and is underlain by Provo-age and younger offshore sediments deposited in Pleistocene Lake Bonneville about 15,000-13,000 years ago (attachment 2). Erickson and others (1968) have mapped the soils at the site as fine sandy loam of the Kidman series. Sediments at the site are expected to consist primarily of fine sands, silts, and clays which have Unified Soil Classifications of ML, CL, and ML-CL. Clay units with Unified Soil Classifications of CH may be encountered at depth during excavation for the water storage reservoir.

The HAFB Site is located on the western edge of the Weber River delta and sediments consist of Provo-age and younger nearshore and deltaic deposits (attachment 2). Erickson and others (1968) have mapped the soils at the site as well-sorted fine sand with a Unified Soil Classification of SP. Lenses of gravel or silt and clay may be encountered at depth during excavation.

### Geologic Hazards

#### Earthquake Ground Shaking

Because both sites are within the Intermountain Seismic Belt and near the Wasatch fault zone, the potential for severe ground shaking accompanying earthquakes is high. Both sites are in Uniform Building Code (UBC) Seismic Zone 3 and Utah Seismic Safety Advisory Council (USSAC) Seismic Zone U-4, the zones of highest seismic risk in Utah in the respective zonations. Recent work by Youngs

and others (1987) indicates a maximum expected ground acceleration in the Clearfield area (10 percent probability of exceedence in 250 years) of 0.7g. The peak acceleration with a 10 percent probability of exceedence in 10 years is 0.06g, and in 50 years is 0.35g. These values should be considered by those designing the structure to insure its seismic safety.

### Liquefaction-Induced Ground Failure

Liquefaction potential maps by Anderson and others (1982) indicate that the potential for earthquake-induced soil liquefaction is moderate at the Park Site and very low at the HAFB Site (attachment 3). Soil liquefaction occurs in areas of shallow ground water (less than 30 feet) and loose sandy soils as a result of increased pore-water pressures. Ground failure may occur due to a loss of shear strength as bearing pressures are transferred from the granular structure of the soil to the pore water which fills the voids between the grains. The probability of ground shaking levels sufficient to induce liquefaction occurring during the next 100 years at the Park Site (0.12 - 0.20g) is 10 - 50 percent, and at the HAFB Site (more than 0.30g) is less than 5 percent. The type of ground failure which may occur as a result of liquefaction depends primarily upon the severity and duration of ground shaking, and on the ground surface slope. Ground surface slopes at both the Park and HAFB sites are between 0.5 and 5.0 percent (Anderson and others, 1982), and therefore liquefaction-induced ground failure could result in lateral spread landsliding at both sites. Lateral spread landsliding could damage the proposed water storage reservoir, and could also damage water conduits attached to the reservoir. To prevent loss of water and subsequent flooding due to conduit failure, valves at the reservoir designed to close if conduits are severed should be considered.

The liquefaction potential maps are at a regional scale and, although they can be used to gain an understanding of probable potential of a given area for liquefaction during earthquake ground shaking, they are not designed to replace site-specific evaluations. Mapped areas rated as having a low liquefaction potential may contain isolated areas with a high liquefaction potential and areas rated as having a high liquefaction potential may contain isolated areas which are not prone to liquefaction (Anderson and others, 1982). It is therefore recommended that an evaluation of liquefaction potential for both of the proposed sites be conducted as part of a soil foundation investigation.

### Tectonic Subsidence

Large-scale tectonic subsidence may accompany surface faulting during large earthquakes on the Wasatch fault as the downthrown (valley-side) block is downdropped and tilted toward the fault. This subsidence may occur over tens of miles west of the surface-fault rupture. Preliminary tectonic subsidence maps for the Wasatch fault zone (Keaton, 1987) indicate that the predicted subsidence due to the "characteristic" Wasatch fault earthquake (Richter magnitude 7.0-7.5) would be about 5 feet near the mountain front, decreasing toward the valley center. Tectonic subsidence could cause a loss of head (less than 5 feet) in the water system. Tectonic subsidence is, in this area, a poorly understood and relatively rare event, occurring only during large surface-faulting earthquakes on the Weber Segment of the Wasatch fault, and thus should not be a major consideration in siting of the water storage reservoir. However, if a head loss of less than five feet is critical at one site and not another, it may be prudent to consider tectonic subsidence.

## Shallow Ground Water

Shallow ground water, associated with either the unconfined water-table aquifer or perched ground water, could occur at either site and adversely affect cut-slope stability during construction of the reservoir. If encountered, ground water may need to be drained from the site. It is recommended that the seasonal high ground-water level at the chosen site be evaluated during a soil foundation investigation, and recommendations given for mitigation of any hazards it poses.

## Problem Soils

Erickson and others (1968) indicate that the soils at the surface at both sites have only a low to moderate shrink-swell potential. Moisture sensitive soils subject to hydrocompaction or with a high shrink-swell potential could be encountered, and it is recommended that potential soil problems at the foundation level be evaluated in a soil foundation investigation. This report should contain recommendations for foundation preparation and construction, and include recommendations concerning cut slopes.

## Other Hazards

Stream flooding, lake flooding, dam-failure inundation, debris flows, landslides, rock fall, and surface-fault rupture are other geologic hazards which affect certain areas along the Wasatch Front. Preliminary Davis County geologic hazards maps indicate that these hazards do not occur at either of the proposed sites, and need not be considered further.

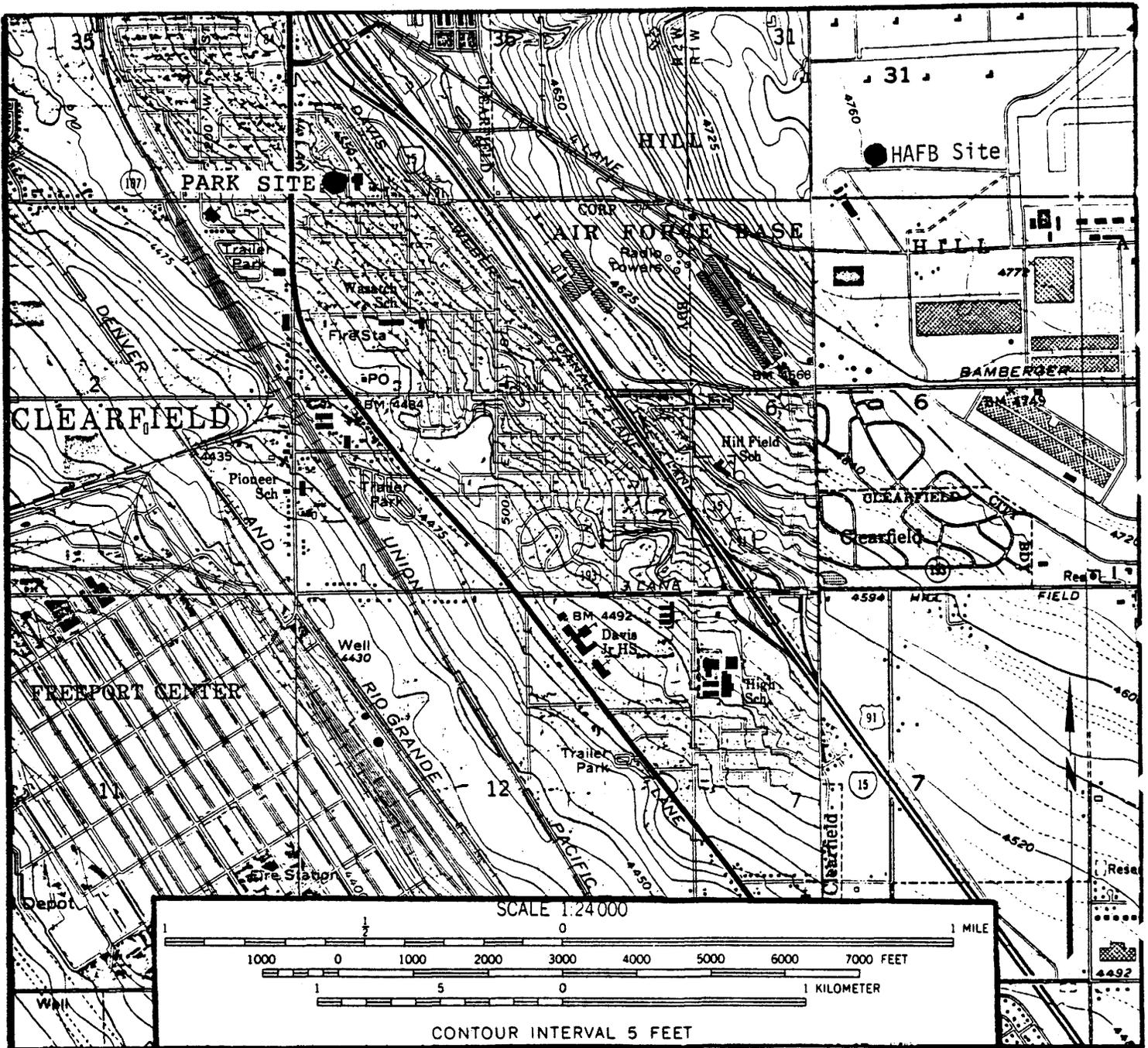
## Conclusions And Recommendations

In conclusion, the HAFB Site is slightly more suitable from a geologic standpoint because the liquefaction hazard is very low, whereas it is moderate at the Park Site. However, this hazard does not make the Park Site unsuitable because structural measures can be taken to mitigate this hazard. Other hazards present at both sites include earthquake ground shaking and tectonic subsidence. The structure can be designed to withstand expected ground shaking levels at either site. Loss of head due to tectonic subsidence accompanying a large surface-faulting earthquake in the area can be considered if it is critical, but need not be a major factor in choosing a site because the amount of expected subsidence can only be estimated, and because the hazard is poorly understood and relatively unlikely to occur. A site-specific soil foundation investigation is recommended at either site to evaluate liquefaction potential and soil foundation and shallow ground water conditions, and to make recommendations concerning foundation design. Please contact me if you have any questions, and let me know when the excavation is open so that I may inspect it as part of my data collection effort.

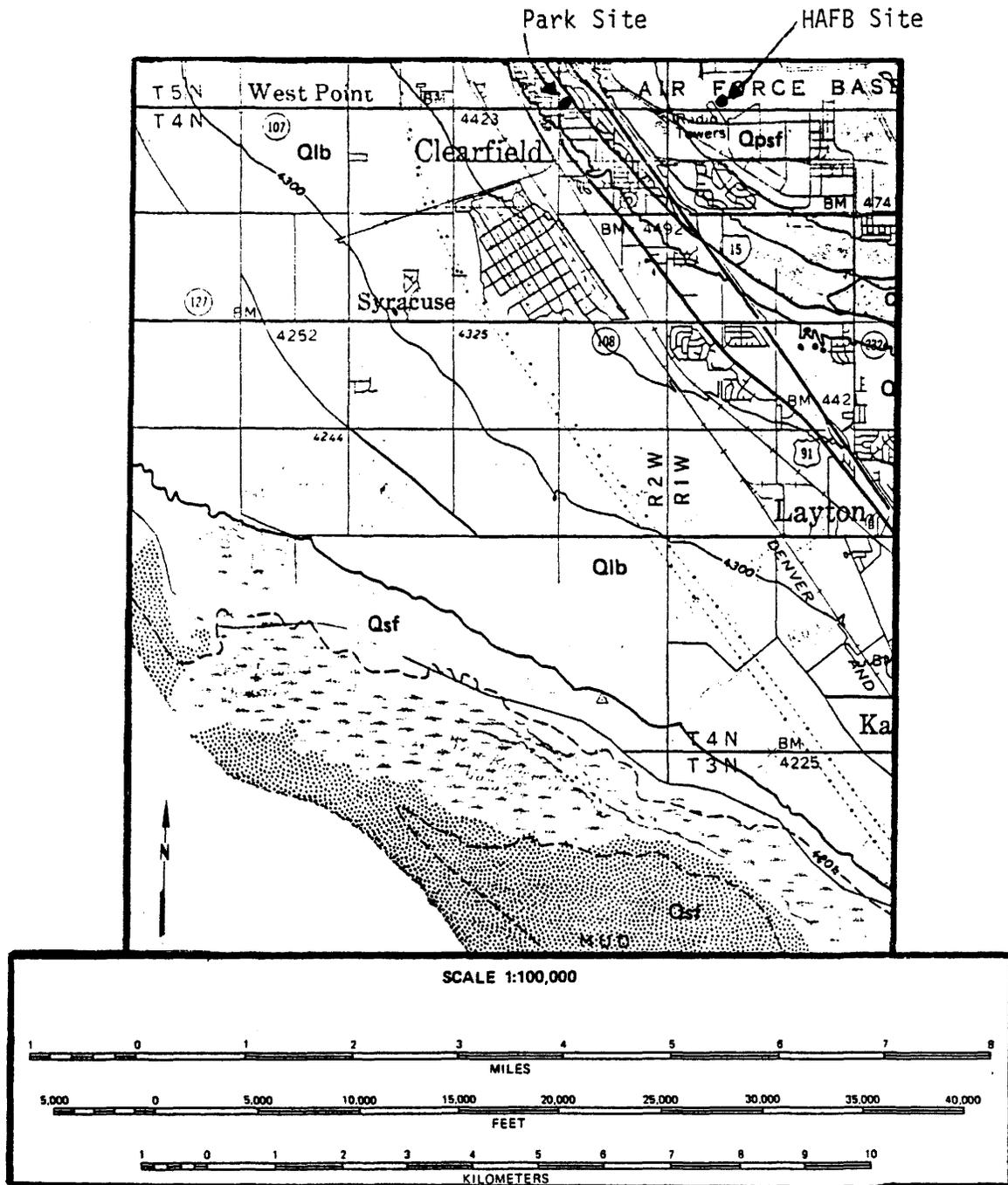
## References Cited

- Anderson, L. R., Keaton, J. R., Aubry, Kevin, and Ellis, S. J., 1982, Liquefaction potential map for Davis County, Utah: Department of Civil and Environmental Engineering, Utah State University, Logan, Utah, and Dames and Moore Consulting Engineers, Salt Lake City, Utah, 50 p.

- Currey, D. R., and Oviatt, C. G., 1985, Durations, average rates, and probable causes of Lake Bonneville expansions, stillstands, and contractions during the last deep-lake cycle, 32,000 to 10,000 years ago, in Kay, P. A., and Diaz, H. F., eds., Problems of and prospects for predicting Great Salt Lake levels: Conference Proceedings, University of Utah Center for Public Affairs and Administration, Salt Lake City, Utah, p. 9-24.
- Davis, F. D., 1983, Geologic map of the Central Wasatch Front: Utah Geological and Mineral Survey Map 54-A, 1:100,000 scale.
- Erickson, A. J., Wilson, L. W., Hughie, V. K., Nielson, Woodrow, and Chadwick, R. S., 1968, Soil Survey of Davis-Weber area, Utah: United States Department of Agriculture Soil Conservation Service, in cooperation with Utah Agriculture Experiment Station, 149 p.
- Keaton, J. R., 1987, Potential consequences of earthquake-induced tectonic deformation along the Wasatch Front, Utah: Department of Civil and Environmental Engineering, Utah State University, Logan, Utah, 1:125,000 scale.
- Youngs, R. R., Swan, F. H., Power, M. S., Schwartz, D. P., and Green, R. K., 1987, Probabilistic analysis of earthquake ground shaking hazard along the Wasatch Front, Utah, in Gori, P. L., and Hays, W. W., eds., Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U. S. Geological Survey Open-File Report 87-585, v. 2, p. M-1 - M-110.



Location Map

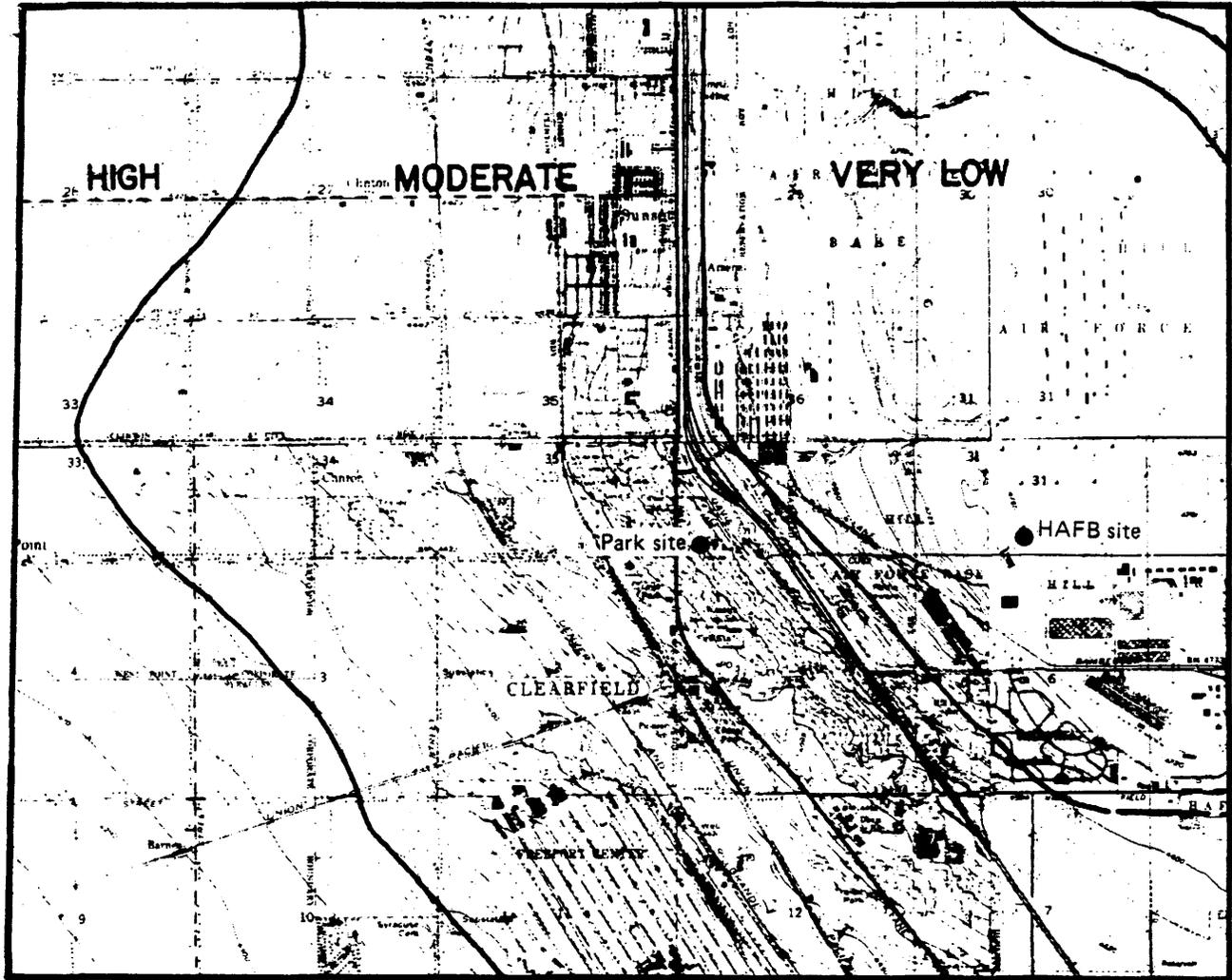


Geologic Map

**EXPLANATION**

- Qac = Bonneville offshore deposits; mainly clay, silt, and fine sand in thin beds.
- Qlb = Provo and younger offshore deposits; mainly clay, silt, sand, and, locally, offshore sand bars.
- Qpsf = Provo and younger nearshore and deltaic deposits; mainly sand and gravel.
- Qsf = Post-Lake Bonneville salt flat deposits; mainly silt and clay with high salt content.

Source: Davis, F. D., 1983, Geologic map of the Central Wasatch Front: Utah Geological and Mineral Survey Map 54-A, 1:100,000 scale.



Liquefaction Potential Map  
1:48,000 scale

Source: Anderson and others, 1982.

WEBER COUNTY

<b>Project:</b> Report of Geologic reconnaissance: landslide southwest of Gibbons and Reed Co. north pond, west of Uintah, Weber County			<b>Requesting Agency:</b> Weber County Engineering	
<b>By:</b> Mike Lowe	<b>Date:</b> 7-22-85	<b>County:</b> Weber		<b>Job No.:</b> W1
<b>USGS Quadrangle:</b> Ogden				

At the request of Curtis Christensen, Weber County Engineer, an inspection was made of the north pond and surrounding area at the Gibbons and Reed Company property west of Uintah (6194 S. 1550 E., Uintah Bench; figure 1). The pond occurs naturally in a shallow depression along a flat-bottomed drainage. A man-made embankment on the southwest end of the pond has increased the pond's size and depth. Downstream to the southwest, the drainage has cut a deep gully which is eroding headward (northeast) toward the pond (figure 1). Varge J. Lowe (oral commun., 1985), Office Manager for Gibbons and Reed Co., states that landsliding and erosion have caused the head of the gully to move 60 feet closer to the pond since 1980. To stop this erosion, an overflow drain was placed at the pond outlet and water was piped to the base of the hill where it eventually was discharged to the Weber River. However, in 1983 a landslide on the east slope of the valley south of the pond destroyed the overflow pipe. As a result of the 1983 landslide, Weber County installed a new drain in the pond. This new drain was placed in the bottom of the pond in order to completely drain it. A new drainage pipe was also installed. This drainage pipe was buried in the gully which runs southwest from the pond (figure 2).

The purpose of this study was to determine: 1) the nature of the 1983 landslide, and 2) the extent to which pond leakage contributed to ground-water conditions which may have triggered the slide. The scope of the investigation included field inspections on July 10, 1985, and on July 19, 1985, and a review of pertinent geologic literature. Gary Christenson of the Utah Geological and Mineral Survey was present during the field inspection on July 19, 1985. Personal observations made at the site during spring 1979 and 1980, and fall 1983 and 1984, were also used to evaluate the problem.

The pond is in the Washington Terrace landslide complex, an area of extensive landsliding that has been studied previously by Feth (1955), Schroder (1971), Pashley and Wiggins (1972), and Van Horn and others (1972). A number of conditions exist which make this area susceptible to landsliding. The materials in which the landsliding takes place are cyclically bedded sands, silts, and clays representing deep-water deposits of Lake Bonneville over which deltaic cobbles, gravel, and sand have been deposited. The Weber River has cut into these deposits as the lake retreated, creating a steep 200-foot high bluff. Compounding the problem of slope steepness and slide-prone materials is the presence of ground water. Many springs are found on the hillside where impermeable clay beds in the lake sediments prevent further downward movement of ground water and develop perched water tables in the slope. Schroder (1971) states that the clays and sands in the slopes are prone to sliding when saturated. Piping caused by exiting ground water may also contribute to the problem. Landslides in this type of environment usually consist of rotational slumps which mobilize into earthflows, debris flows, or mudflows at the toe of the slump.

The 1983 landslide was probably initiated as a rotational slump but was sufficiently wet to mobilize into a rapid earthflow at the toe. Additional water was probably contributed as the drainage pipe at the top of the slump ruptured (figure 2). The 1983 landslide is part of a larger landslide complex in the valley south of the pond (figure 2). Extensive landsliding has occurred on both the east and west slopes, and the main scarp of a valley-bottom slope failure traverses cross-valley just below the pond. Springs are present at the base of this scarp in the valley bottom, and it is likely that these springs drain a perched aquifer that is recharged by infiltrating pond and stream water. Other springs and seeps occur at similar and lower elevations in the east and west slopes of the valley (figure 2). The source of this water may include some seepage from the pond, but also includes areas on the bench top.

In conclusion, it is likely that ground water was a major contributing factor causing the 1983 landslide. It is not known how much of this ground water was attributable to pond leakage, but it is possible that draining the pond has aided in stabilizing the 1983 landslide and other landslides in the area. A dye test with dye placed in the pond (temporarily re-established through plugging of the drain) and monitored at various springs could be performed to help determine ground-water flow in the area. However, this would probably not conclusively establish the role of pond leakage in the 1983 landslide. Also, draining the pond has eliminated the possibility of overflow causing further headward erosion in the gully. Such erosion could ultimately have led to the breaching of the pond causing flooding due to outflow of pond water down the gully.

#### REFERENCES

- Feth, J.H., 1955, Sedimentary features in the Lake Bonneville Group in the east shore area near Ogden, Utah, *in* Eardley, A.J., ed., Tertiary and Quaternary geology of the eastern Bonneville Basin: Utah Geological Society Guidebook to the Geology of Utah, no. 10, p. 37-44.
- Schroder, J.F., 1971, Landslides of Utah: Utah Geological and Mineral Survey Bulletin 90, 51 p.
- Pashley, E.F., Jr., and Wiggins, R.A., 1972, Landslides of the Northern Wasatch Front, *in* Hilpert, S.L., ed., Environmental Geology of the Wasatch Front, 1971, Utah Geological Association Publication 1, Salt Lake City, Utah, p. K1-K16.
- Van Horn, R., Baer, J.L., and Pashley, E.F., Jr., 1972, Landslides along the Wasatch Front, Utah, *in* Hilpert S.L., ed., Environmental Geology of the Wasatch Front, 1971, Utah Geological Association Publication 1, Salt Lake City, Utah, p. J1-J16.

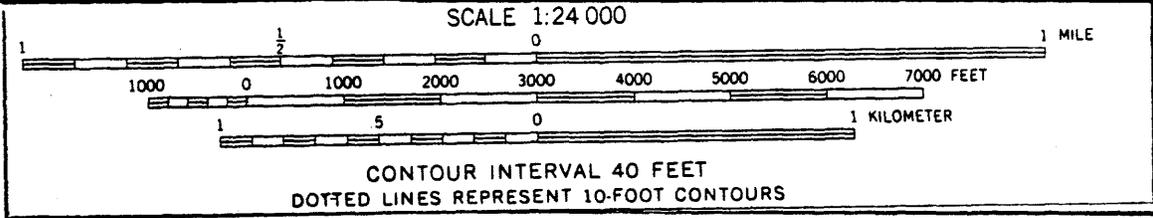
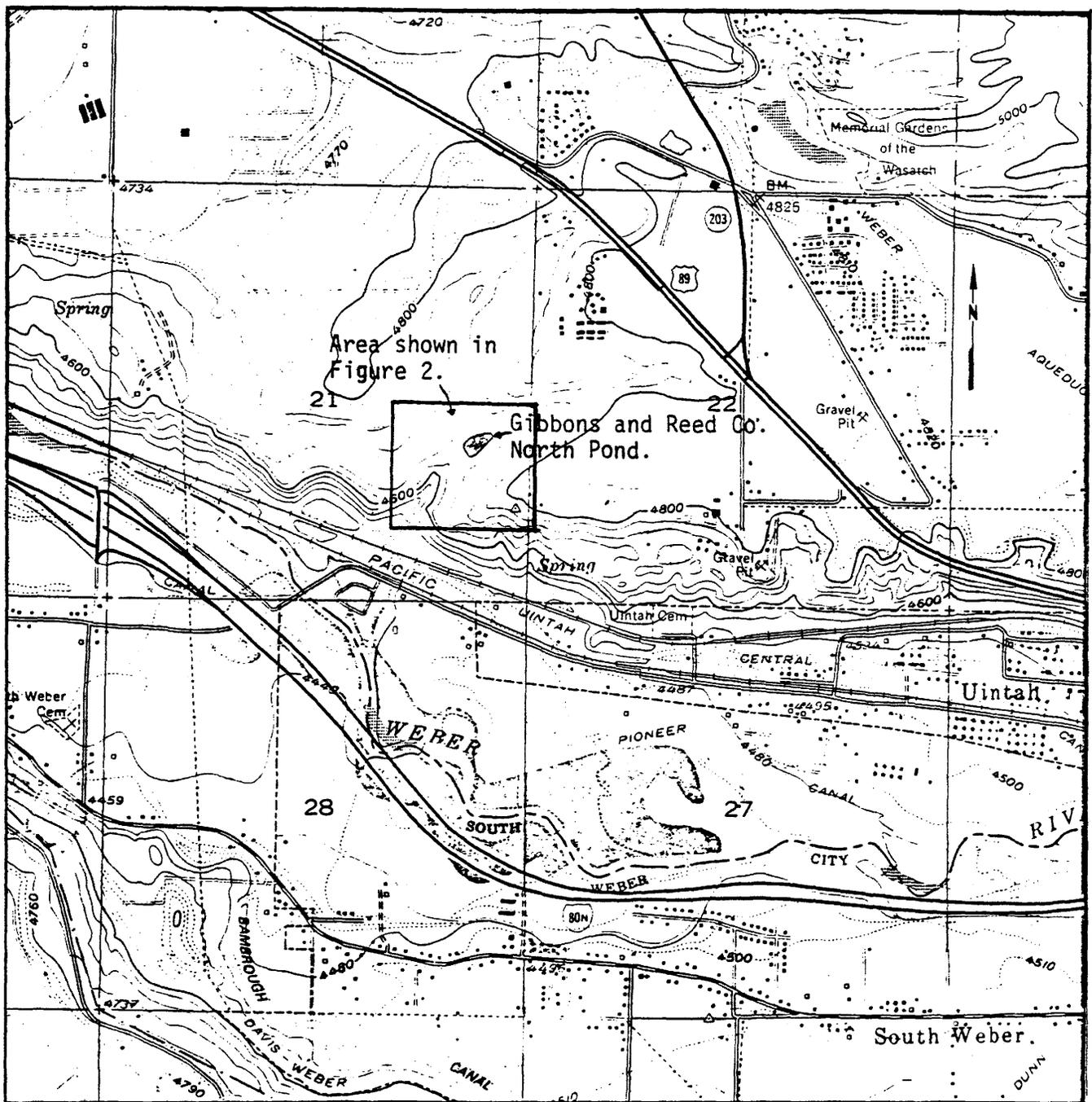
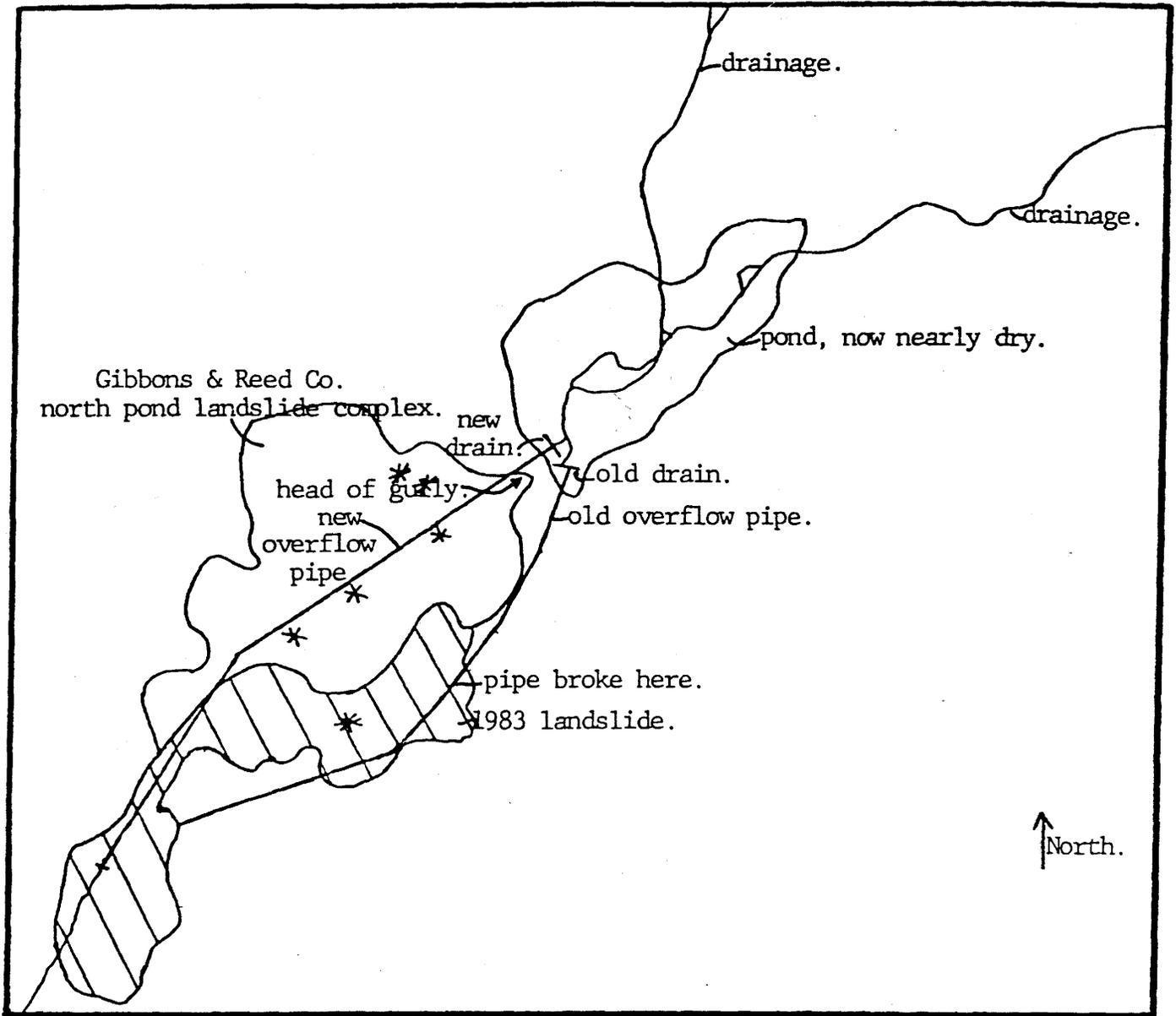


Figure 1. Location map.



\* - spring area.

 - 1983 landslide.

Figure 2. Generalized map view of Gibbons & Reed north pond landslide complex.

<b>Project:</b> Investigation of landslide at approximately 5931 South Weber Drive, Riverdale, Utah		<b>Requesting Agency:</b> Weber County Engineering	
<b>By:</b> Mike Lowe	<b>Date:</b> 11-8-85	<b>County:</b> Weber	<b>Job No.:</b> W2
<b>USGS Quadrangle:</b> Ogden			

On September 30, 1985, at the request of John Reeve, Weber County Engineer, an inspection was made of a landslide located along the bluff on the south side of the Weber River in Weber County at approximately 5931 South Weber Drive, Riverdale, Utah. The landslide is of concern to Weber County because there are seven houses that have been or are being affected by the landslide. The purpose of this inspection was to determine the factors affecting movement of the landslide, particularly the extent to which water leaking from the Weber-Davis canal may be contributing to this movement. The scope of work included a review of pertinent literature, analysis of air photos, and a two-hour field reconnaissance on September 30, 1985. Bruce Kaliser (Utah Geological and Mineral Survey), Tom Hoover (Weber-Davis Canal Company), Randy Daily (Riverdale City Building Inspector), David L. Shank, Jr. (Dames and Moore), Max Holbrook (property owner 5931 South Weber Drive), and John and Debbie Flynn (property owners 5925 South Weber Drive) were contacted and provided information which aided this investigation.

The bluff on which the landslide occurs is in an area referred to as the South Weber Landslide Complex (Pashley and Wiggins, 1972). The landslide is a rotational slump about 800 feet wide in gravel to clay-size sediments of the Weber River Delta, deposited by the Weber River as it flowed into Lake Bonneville. Downcutting by the Weber River into the delta following the disappearance of Lake Bonneville has created steep slopes bordering the river along which many landslides occur.

The landslide on South Weber Drive is a reactivation of an older landslide. The time of initial movement of the older landslide is not known, but the landslide was apparently stable until February of 1983, as the Flynn house had been built on the toe of this landslide about 40 years ago, but no signs of stress were noted by John Flynn until February 1983. At that time, renewed movement by the landslide began and by June of 1983, according to Bruce Kaliser (letter to Riverdale City Council dated June 28, 1983), active landsliding was affecting seven homes on the landslide. Max Holbrook stated that movement on the landslide continued in 1985 and that most of the damage to this house located on the toe of the landslide occurred in 1985. Instruments placed at the head of the landslide by Bruce Kaliser indicate that movement continued into 1984 but that the head of the landslide has not moved in 1985. From these observations by Mr. Holbrook and Mr. Kaliser, it appears that parts of the slide mass continue to move but that other parts have stabilized.

Factors which may have contributed to the 1983 reactivation of the landslide include: 1) changes in ground-water conditions due to unusually high precipitation, lawn water or other water applied to the surface from residences on the landslide or above it, and water which may be leaking into the landslide area from the Weber-Davis Canal, and 2) disruption in the toe area caused by

area from the Weber-Davis Canal, and 2) disruption in the toe area caused by construction of a new sanitary sewer along South Weber Drive or by other grading and landscaping related to development. Factors which may be contributing to the continuing movement on the landslide reported by Mr. Holbrook include the cumulative affects of several years of above-normal precipitation, lawn water from surrounding residences, and water which may be leaking into the landslide area from the Weber-Davis Canal.

Above-normal precipitation in 1983 and 1984 destabilized slopes and caused the reactivation of many landslides in Utah. This excess precipitation is likely to have been a major factor causing reactivation of the landslide in question. A return to normal or below-normal precipitation in 1985 may be responsible for the apparent stabilization of parts on the landslide as indicated by instruments at the head of the landslide, although movement in part of the toe area apparently continues as indicated by Mr. Holbrook. It is possible that renewed movement of the 1983 landslide mass may occur.

Lawn water from residences in the area may be infiltrating into the landslide area. The contribution of lawn water to the 1983 reactivation of the landslide cannot be evaluated without knowing the aquifer characteristics which determine ground-water travel time. Lawn water may be contributing to the continuing movement on the landslide, as reported by Mr. Holbrook, and a reduction in the application of water to the surface may help to stabilize it.

The Weber-Davis Canal, which according to Tom Hoover was constructed over a hundred years ago, flows west along the bluff above the landslide. The canal is cement-lined through the area and, although the lining is cracked and deteriorating in many places, the lining appears to be largely intact in the area above the landslide. Water may be leaking through the canal lining and infiltrating into the landslide area. The state of the canal lining in 1983 is not known, but there are signs of recent patching in only one area above the landslide. The contribution of canal water to the 1983 reactivation of the landslide cannot be evaluated without knowing whether leakage is occurring or knowing the subsurface stratigraphy and the aquifer characteristics which determine ground-water travel paths and time. Water which may be leaking from the canal could contribute to current or future movement on the landslide. Various tests can be performed to determine if water is leaking from the canal in the vicinity of the landslide. Two such tests could be done by damming a section of the canal above the landslide and either: 1) placing dye in the canal and monitoring the flowing spring above the home at 5925 South Weber Drive, or by 2) placing a known quantity of water in that section of the canal and monitoring loss of water. Water which would have been lost due to evaporation could be calculated so that water lost due to infiltration could be determined. Comparisons of spring flow on the landslide with periods of flow in the canal may also provide useful information. If the canal is found to be contributing water to the landslide area, it could be reduced by repairing the canal lining in the vicinity.

A sanitary sewer line was constructed in February of 1983 along South Weber Drive by L. March & Sons, Inc. for Riverdale City according to Mrs. Flynn. This line and South Weber Drive apparently cross the toe of the landslide in at least one place as movement on the landslide caused a section of the road to be uplifted in 1983 (Randy Daily, oral commun., 1985). The location of this uplifted section of road is near the east side of the landslide as marked by a

visible bulge in the road and recent road repair. Bruce Kaliser (oral commun., 1985), however, has stated that he has no evidence South Weber Drive and the sanitary sewer line cross the toe of the landslide. Details of the sewer-line excavation were not available from L. March & Sons, Inc. as the company is no longer in business and former company officials could not be contacted. Details of the sewer-line excavation were requested from Riverdale City but were not available. Debbie Flynn has stated that the sewer-line excavation was approximately 15 feet deep and 20 feet wide, and that, because of heavy rains, the excavation was left open for approximately three weeks. Max Holbrook, Randy Daily, Tom Hoover, and John and Debbie Flynn have all stated that they first became aware of damage to the homes on the landslide during or immediately after construction of the sanitary sewer line. The coincidence of movement on the landslide and construction of the sewer down South Weber Drive indicates that excavation of the trench for the sewer line may have contributed to the reactivation of the landslide. It is noted, however, that the heavy rains which delayed construction could also have contributed.

In conclusion, several possible factors affecting the stability of the landslide have been identified. Some methods for evaluating the extent these factors are affecting the landslide have been suggested. Lining of the canal, if found to be leaking, and a reduction of lawn watering may reduce infiltration into the landslide and help to stabilize it. Emplacement and monitoring of piezometers and monitoring of discharge from springs would be required to further evaluate the role of ground water in landsliding. Comparison of these records with climatological data and canal flow rates may help identify sources of recharge, but these data may not be definitive in terms of determining the cause of the 1983 movement. Much of the information regarding the history of landslide movement for this report was obtained by interviewing the people involved. This information conflicts in some cases and verification through field observations and written documentation is generally not possible. In order to properly document events for future use, detailed mapping and periodic remapping of existing surface landslide features (cracks, scarps, etc.), systematic monitoring of damage to homes, and/or instrumental measurement of ground movement is recommended. To help evaluate the possible role of the sewer-line excavation in initiating movement in 1983, subsurface investigations to determine the depth to the basal slide plane and to better define the toe of the landslide are needed. Based on the present investigation, the relative contribution of each factor to the initiation and continuation of movement of the landslide cannot be determined. However, because continued movement is possible, it is recommended that the necessary studies be performed to determine if the slope can be stabilized and if so, the best method of stabilization.

#### REFERENCES

- Pashley, E.F., Jr., and Wiggins, R.A., 1972, Landslides of the Northern Wasatch Front, *in* Hilpert, S.L., ed., Environmental Geology of the Wasatch Front, 1971, Utah Geological Association Publication 1, Salt Lake City, Utah, p. K1-K16.

Project: Combe Road landslide		Requesting Agency: Weber County Engineering	
By: Mike Lowe	Date: 3-25-88 76	County: Davis Weber	Job No.: W3
USGS Quadrangle: Ogden			

At the request of John Reeve, Weber County Engineer, two one-hour field inspections of a landslide located in the SE 1/4 SE 1/4 sec. 15, T. 5 N., R. 1 W. just north of Combe Road were made on March 13, 1986 and March 24, 1986. John Reeve and Bill Gordon (Dames & Moore Consulting Engineers) were present during the March 24 field inspection. The purpose of these field inspections was to examine the active landslide and assess the possibility of further movement. The scope of work for this investigation included the two field inspections, analysis of aerial photographs, and a review of pertinent literature.

The material involved in the landsliding consists of horizontal, cyclically bedded clays, silts, and fine sands of lacustrine origin (Feth and others, 1966) and overlying man-placed fill. The horizontal beds were deposited by Pleistocene-age Lake Bonneville when the lake was at its maximum between about 14,500 - 16,000 years ago (Currey and others, 1984). Fill was later brought in by man, first when the cemetery north of the landslide was initially constructed and later when the cemetery expanded to the east. The slope on which the failure occurred is vegetated, but has been oversteepened by stream downcutting and lateral erosion during the Provo stage of Lake Bonneville as the older, higher delta was incised between about 14,500 to 13,500 years ago (Currey and others, 1984). Grading for construction of Combe Road may also have undercut the slope. The slope has had a number of landslide events which have formed a landslide complex about 800 feet long. Most of the landslide complex is not presently active. The active part is located just west of the center of the older landslide complex. For your information, a table and diagram illustrating the landslide classification and terminology used in this memo are included (attachment 1). The initial failure was probably an earth slump which became an earth flow at the foot of the landslide. The main scarp is nearly vertical and was estimated to be about 120 feet long. The main scarp above the center of the head of the landslide was estimated to be about 20 feet high, with approximately 17 feet of the material forming the scarp being fill, and the lower 3 feet being lacustrine clays, silts, and fine sands. The scarp at the west flank is about 3 feet high near the head of the landslide. The landslide deposit was estimated to be 100 feet long from head to toe, 120 feet wide near the head, and up to 20 feet thick. Water was noted exiting the main scarp at approximately the elevation of the head. The volume of water was estimated to be 10 to 15 gallons per minute on March 13. By March 24 flow had decreased to 1 to 3 gallons per minute.

Because steep slopes remain and water exiting the main scarp in the head area is infiltrating into the landslide, further failure at this location is likely. Lateral shear cracks along both flanks and crown cracks above the head were observed during the March 13 field inspection. This landslide is presently affecting Combe Road where toe material must be periodically removed to keep the road open. Continued growth of the landslide in the main scarp area may endanger the cemetery road to the north which is presently 26 feet from the main scarp.

the cemetery road to the north which is presently 26 feet from the main scarp.

In conclusion, the Combe Road landslide is likely to continue to be active unless remedial measures are taken. Combe Road and, to a lesser extent, the cemetery road may be affected by future landsliding. Remedial measures have been suggested by Dames and Moore. The present solution, which is to remove toe material as it affects Combe Road, encourages further landslide activity and is not a permanent solution.

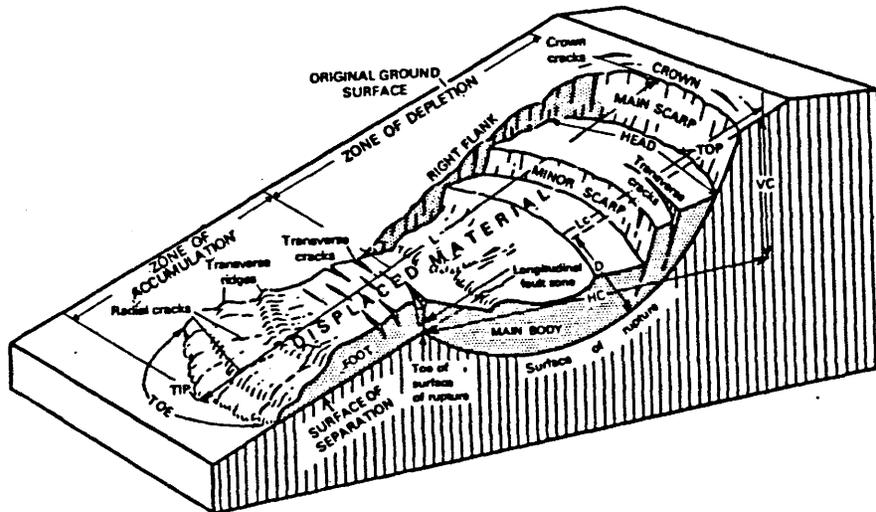
#### REFERENCES CITED

Currey, D. R., Atwood, Genevieve, and Mabey, D. R., 1984, Major levels of the Great Salt Lake and Lake Bonneville: Utah Geological and Mineral Survey Map 73, scale 1:750,000.

Feth, J. H., Barker, D. A., Moore, L. G., Brown, R. J., and Veirs, C. E., 1966, Lake Bonneville: Geology and hydrology of the Weber Delta District, including Ogden, Utah: U. S. Geological Survey Professional Paper 518, 76 p.

Attachment 1

TYPE OF MOVEMENT			TYPE OF MATERIAL		
			BEDROCK	ENGINEERING SOILS	
				Predominantly coarse	Predominantly fine
FALLS			Rock fall	Debris fall	Earth fall
TOPPLES			Rock topple	Debris topple	Earth topple
SLIDES	ROTATIONAL	FEW UNITS	Rock slump	Debris slump	Earth slump
	TRANSLATIONAL		Rock block slide	Debris block slide	Earth block slide
		MANY UNITS	Rock slide	Debris slide	Earth slide
LATERAL SPREADS			Rock spread	Debris spread	Earth spread
FLOWS			Rock flow (deep creep)	Debris flow (soil creep)	Earth flow
COMPLEX			Combination of two or more principal types of movement		



Source:  
 Varnes, D. J., 1978, Slope movements types and processes, in Schuster, R. L., and Krizek, R. J., eds., Landslides, Analysis and Control: National Academy of Sciences, Transportation Research Board Special Report 176, p. 11 - 33.

Project: Causey Estates landslide		Requesting Agency: Weber County Building Inspection	
By: Mike Lowe	Date: 6-2-88	County: Weber	Job No.: W4
USGS Quadrangle: Causey Dam			

At the request of Stuart Patterson, Weber County Building Inspector, a field inspection was made of a landslide located in the SW 1/4 SE 1/4 SE 1/4 sec. 14, T. 6 N., R. 3 E. (attachment 1) on the east side of the Skull Crack Canyon drainage on June 6, 1986. Bruce Kaliser, State Hazards Geologist with the Utah Geological and Mineral Survey, was present during the field inspection, the purpose of which was to assess the possibility of continued movement on the landslide. The scope of investigation included the field inspection of the site and surrounding area, a review of pertinent literature, and an examination of aerial photographs (1980, approximately 1:40,000 scale).

The material involved in the landsliding consists of reddish-brown, poorly stratified, poorly consolidated, sandy clayey silt containing a few rounded pebbles and some fine sand horizons. Mullens (1969) has mapped this area as undifferentiated Wasatch and Evanston Formations (attachment 2) of Upper Cretaceous, Paleocene, and Eocene ages (about 84 million to 36 million years before present). The upper formation, the Wasatch, is mainly variegated mudstone and scattered beds of conglomerate grading westward into reddish-brown mudstone (Mullens 1971). It is probable that the material involved in the landsliding is derived from the reddish-brown mudstone facies of the Wasatch Formation.

The slope on which the failure occurred is a small ephemeral drainage. The slope is vegetated with conifers, aspen, and smaller plants. The slope above the head is about 16 percent, near the head is about 24 percent, and near the center of the landslide steepens to about 30 percent. Most of the surrounding slopes appear to be steeper. For your information, a table and diagram illustrating the landslide classification and terminology used in this memo are included (attachment 3).

The timing of the initial failure is not precisely known, but information from Huntsville residents indicates that it probably occurred on or near May 20, 1986, as this was the approximate date that Causey Reservoir and the South Fork of the Ogden River turned reddish-brown. Mountain bluebells, which were buried by about 6 inches of material from the landslide, had grown through the landslp. No evidence was found that the landslide blocked the creek, although material from the slide definitely reached it and was carried downstream as a mud flow (rapid earth flow).

Scarp heights at both the head and flanks were approximately 15 feet. The landslide was estimated to be 350 feet long and averaged 100 feet in width, with the widest part about 150 feet wide and the narrowest part about 40 feet wide. The slope of the scar near the head was about 38 percent. Several seepage areas were located near the head of the landslide about 15 feet below the top of the main scarp. The amount of water from all the seepage areas combined was estimated at about one gallon per minute. The earth-flow channel from the upper

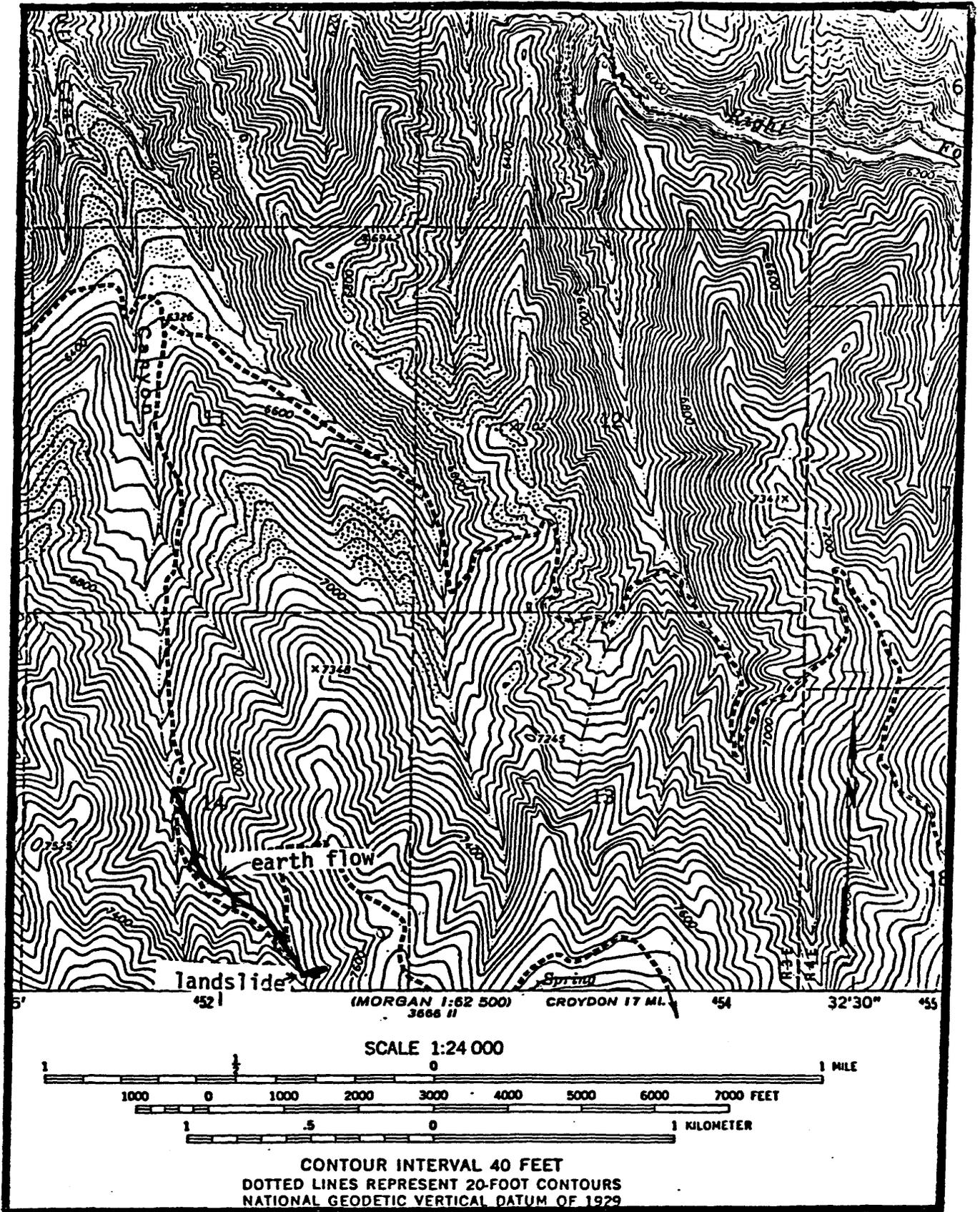
main scarp is presently located. This was followed by a earth flow from the left flank about 100 feet below the present location of the main scarp. No evidence was found that the landslide blocked the creek, although material from the slide definitely reached it and was carried downstream as a mud flow (rapid earth flow).

Scarp heights at both the head and flanks were approximately 15 feet. The landslide was estimated to be 350 feet long and averaged 100 feet in width, with the widest part about 150 feet wide and the narrowest part about 40 feet wide. The slope of the scar near the head was about 38 percent. Several seepage areas were located near the head of the landslide about 15 feet below the top of the main scarp. The amount of water from all the seepage areas combined was estimated at about one gallon per minute. The earth-flow channel from the upper event measured 16.5 feet wide. The majority of the landslide mass reached the creek channel and was carried downstream as a mud flow, but part of the landslide mass near the creek was estimated to be about 15 feet thick. The mud flow from the landslide event reached about 3,300 feet down Skull Crack Canyon, at which point it became a debris flood which flowed into Causey Reservoir. Damage caused by the landslide included broken trees more than 18 inches thick and blockage of the upper part of the Causey Estates road at two locations. As of June 6, 1986, access to two houses was still blocked off by mud-flow material. One house was within 50 feet of being damaged by mud-flow material.

No crown cracks were noted above the landslide, but lateral shear cracks were noted on both sides of the landslide. This would indicate that there is some possibility of future failure but it is felt that the amount of material involved would be much smaller than that which has already failed. Should any failure occur in the future, it is possible that the road could again be blocked. Future landslide events from this location present no danger to existing houses. This landslide occurred in an area which gave no indication of landslide hazard. Surrounding slopes are steeper than the area which failed. Although reconnaissance of the area did not identify any other slope failures in the vicinity, slope stability should be considered when siting future buildings in the area.

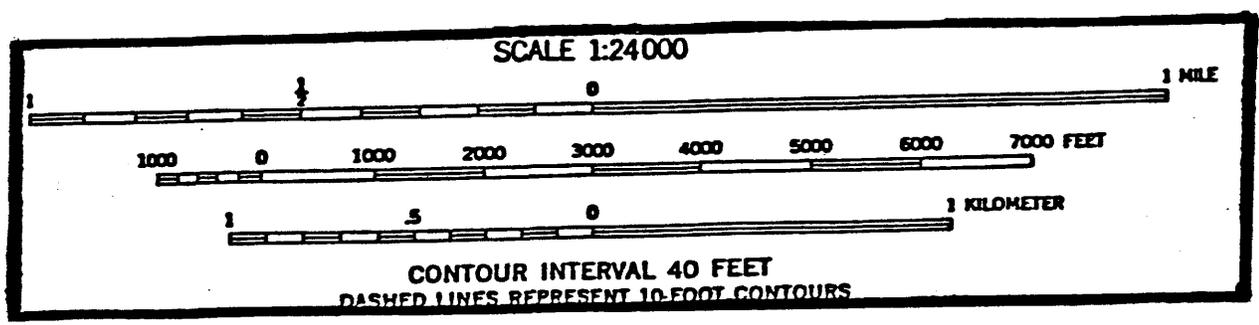
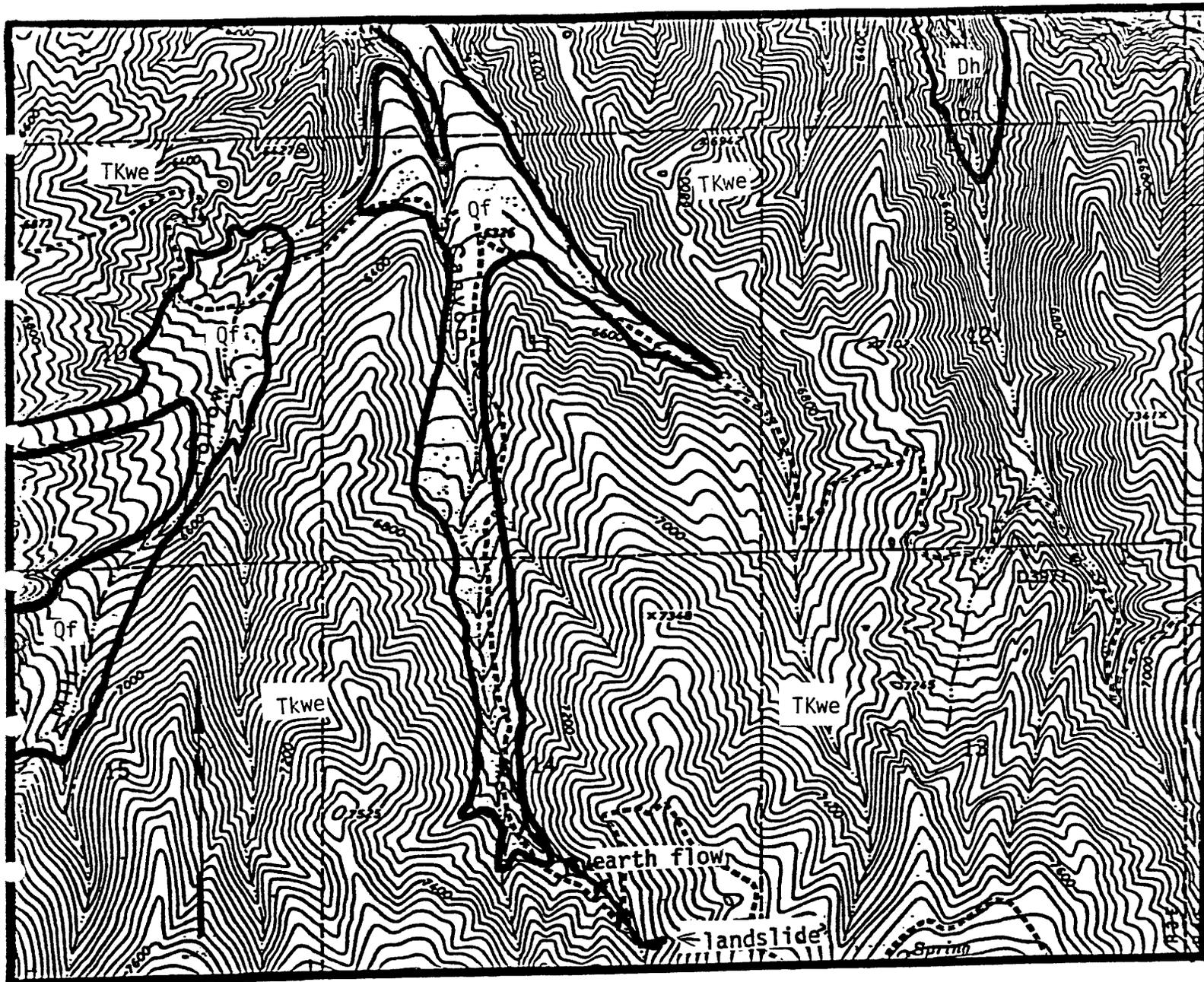
#### REFERENCES CITED

- Mullens, T. E., 1969, Geologic map of the Causey Dam Quadrangle, Weber County, Utah: U. S. Geological Survey Map GQ-790, 1:24,000 scale.
- Mullens, T. E., 1971, Reconnaissance study of the Wasatch, Evanston, and Echo Canyon Formations in part of Northern Utah: U. S. Geological Survey Bulletin 1311-D, 31 p.



Location Map

Base map from: U. S. Geological Survey 7 1/2 min. topo. quad. Causey Dam, Weber County, Utah

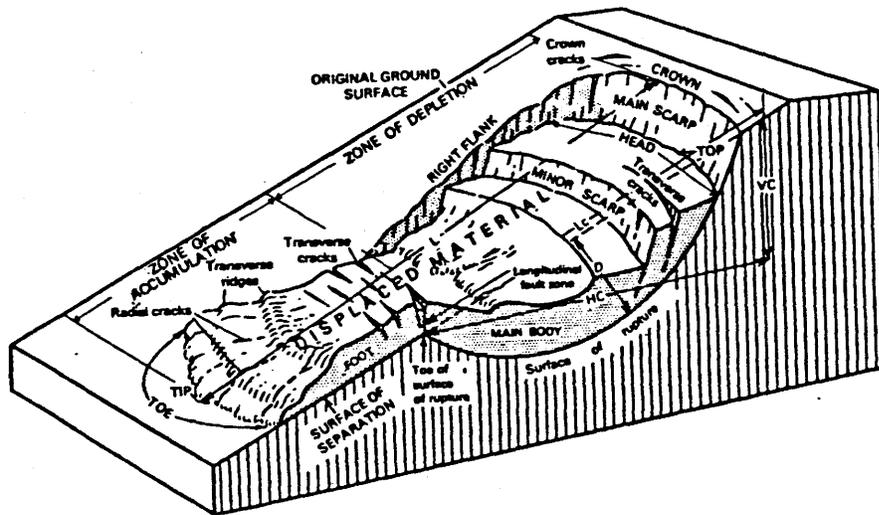


Geology

TKwe = Wasatch and Evanston Formations    Qf = Quaternary fanglomerate  
 Dh = Hyrum Dolomite  
 From: Mullens, T. E., 1969, Geologic map of the Causey Dam Quadrangle, Weber County, Utah: U. S. Geological Survey Map GQ-790, 1:24,000 scale.

Attachment 3

TYPE OF MOVEMENT		TYPE OF MATERIAL			
		BEDROCK	ENGINEERING SOILS		
			Predominantly coarse	Predominantly fine	
FALLS		Rock fall	Debris fall	Earth fall	
TOPPLES		Rock topple	Debris topple	Earth topple	
SLIDES	ROTATIONAL	FEW UNITS	Rock slump	Debris slump	Earth slump
	TRANSLATIONAL		Rock block slide	Debris block slide	Earth block slide
			MANY UNITS	Rock slide	Debris slide
LATERAL SPREADS		Rock spread	Debris spread	Earth spread	
FLOWS		Rock flow (deep creep)	Debris flow (soil creep)	Earth flow	
COMPLEX		Combination of two or more principal types of movement			



Source:  
 Varnes, D. J., 1978, Slope movements types and processes, in Schuster, R. L., and Krizek, R. J., eds., Landslides, Analysis and Control: National Academy of Sciences, Transportation Research Board Special Report 176, p. 11 - 33.

<b>Project:</b> Proposed water tank site, NE 1/4, SE 1/4, SW 1/4 sec. 22, T. 7 N., R. 1 E., just south of the Wolf Creek Development near Eden, Utah		<b>Requesting Agency:</b> Eden Water Works	
<b>By:</b> Mike Lowe	<b>Date:</b> 7-9-87	<b>County:</b> Weber	<b>Job No.:</b> W5
<b>USGS Quadrangle:</b> Huntsville			

### INTRODUCTION

At the request of Jay Gould, President of Eden Water Works, an investigation of a proposed site for a 500,000-gallon buried water tank was performed. The proposed site is in the NE 1/4 SE 1/4 SW 1/4 sec. 22, T. 7 N., R. 1 E., just south of the Wolf Creek Development near Eden in Ogden Valley, Weber County, Utah (attachment 1). The purpose of this investigation was to identify any geologic hazards affecting the site. The scope of work for this investigation included a literature search, a one-hour field investigation on June 22 and a three-hour field investigation on July 7, 1987, and an examination of aerial photographs (1966, approximate scale 1:28,000; 1980, approximate scale 1:40,000). Mr. Gould was present during the June 22 field inspection.

### General Geology

The site is northwest of an unnamed drainage at an elevation of approximately 5,180 feet, coincident with the highest level reached by Pleistocene Lake Bonneville about 16,500 to 15,000 years ago (Currey and Oviatt, 1985). The unconsolidated sediments at the surface in the northeastern portion of the site range in grain size from boulders to clay. These deposits have been mapped by Sorensen and Crittenden (1979) as Holocene-age, bouldery colluvium and slopewash which is in part made up of residual lag deposits from Tertiary rocks (attachment 2). Some of the sediments at the surface in the northeastern portion of the site are probably alluvial-fan deposits of the unnamed drainage southeast of the site. This drainage has subsequently eroded down through these deposits, and alluvial-fan deposition no longer takes place at the site. In the southwestern portion of the site, these sediments are overlain by fill which contains large boulders and cement blocks. No subsurface investigations were conducted at the site and, therefore, the materials which will be encountered at depth during excavation for the water tank are not known. Areas of weathered Norwood Tuff in the general vicinity of the site (attachment 2), including unmapped areas about 100 feet southeast and 800 feet southwest of the proposed site, indicate that the Tertiary Norwood Tuff may be encountered at shallow depths during excavation for the water tank. The Norwood Tuff is a fine-grained, easily erodible, white-to-buff weathering, volcanic bedded tuff which was probably waterlain and in part reworked. It is possible that thin Bonneville lake cycle nearshore deposits overlying the Norwood Tuff may also be encountered during excavation.

### Geologic Hazards

#### Earthquake Ground Shaking

Because the site is within the Intermountain Seismic belt and near the East

Because the site is within the Intermountain Seismic belt and near the East Ogden Valley fault zone, the potential for sever ground shaking accompanying earthquakes is high. The site is in Uniform Building Code (UBC) Seismic Zone 3 and Utah Seismic Safety Advisory Council (USSAC) Seismic Zone U-4, the zones of highest seismic risk in Utah in the respective zonations. As a minimum, construction should incorporate earthquake-resistant design required for UBC Seismic Zone 3, with inspection and monitoring by weber County Building Inspectors as outlined for USSAC Seismic Zone U-4.

### Surface-Fault Rupture

The site is located near the northern end of the East Ogden Valley fault zone. Detailed studies have not been conducted for this fault zone and, therefore, recurrence intervals and possible maximum earthquake magnitudes associated with surface-fault rupture events on the fault zone are unknown. Sullivan and others (1986) show the East Ogden Valley fault zone to be approximately 4,000 feet east of the proposed water tank site (attachment 3). Sorensen and Crittenden (1979) have mapped a number of scarps near the site and southwest of the main fault which they attribute to surface faulting (attachment 2). Lofgren (1955), Doyuran (1972), and Sullivan and others (1986) attribute these scarps to landsliding. The land surface east of these scarps slopes toward the northeast. The regional dip of bedrock units in Ogden Valley is also toward the northeast, and therefore these scarps may also have resulted from differential erosion in the Norwood Tuff, with more resistant beds forming northeast dipping platforms over which surficial deposits have been deposited. Exposures 800 feet southwest of the site indicate a dip of about 40° NE, similar to the regional bedding dip. The scarps range from 5 to 20 feet high and have slopes of 9 to 14 degrees (Chen and Associates, 1982). Applying criteria developed by Bucknam and Anderson (1979) and by Wallace (1977) concerning age-dating of fault scarps using regression of fault scarp slopes with time, Chen and Associates (1982) determined that the scarps near the proposed site would have ages in the range of 11,000 to 100,000 years before present. Scarp regression criteria can also be applied to landslide scarps and therefore, if the scarps are due to landsliding, the slope failure probably occurred 11,000 to 100,000 years before present. If the scarps are due to differential erosion, slope regression analyses do not apply.

The origin of these scarps (faulting, landsliding, or differential erosion) is a critical issue with respect to the suitability of the site for the proposed water tank. If the scarps were produced by past surface-faulting, the site may be within the zone of deformation associated with surface-fault rupture. To determine this, a detailed trenching study to identify faults in the subsurface would be required. However, Sullivan and others (1986) interpret the scarps to be the result of shallow landslides or bedrock knobs protruding through the thin surficial deposits rather than faults. No surficial evidence of faulting is present at the site and most other investigators indicate that other explanations for the scarps are more plausible (Lofgren, 1955, Doyuran, 1972). Because of this, it is not believed that a detailed trenching study is necessary, although the excavation for the water tank should be inspected for any signs of past surface-fault rupture.

### Landslides

Lofgren (1955), Doyuran (1972), and Sullivan and others (1986) have

presented evidence which support a landslide origin for scarps near the site. Sullivan and others (1986) point out that landslides in the Norwood Tuff are ubiquitous in the back valleys of the Wasatch Mountains. Based on scarp profiling by Chen and Associates (1982), these scarps, if due to landsliding, have not been active in Holocene time (last 10,000 years). More important, Sullivan and others (1986) do not show the site to be within the boundaries of the landslide (attachment 3). The dip (40° NE) which was taken from the drainage ditch about 800 feet southwest of the site would support the conclusion that landsliding has not occurred in the area, and the landslide hazard at the site, therefore, should be considered low.

### Soil Foundation Conditions

Soil foundation problems may be the most significant potential hazard affecting the site. The Tertiary Norwood Tuff and associated soils have a high shrink-swell capacity and, if poorly indurated, a low bearing strength. These materials are also erodible and may be subject to differential settlement. Because the site is probably on bedrock and shallow ground water is not likely to be encountered, the potential for liquefaction during earthquake ground shaking is probably low. However, a detailed soil foundation investigation should be performed to address these potential problems.

### Other Hazards

Flood maps are not available for the unnamed drainage, but because it has incised well below the proposed water-tank site, flood and debris-flow hazards at the site are low. There are no bedrock outcrops or perched boulders which may present a rock-fall hazard at the site. No reservoirs are present above the site, and therefore, dam failure inundation need not be considered.

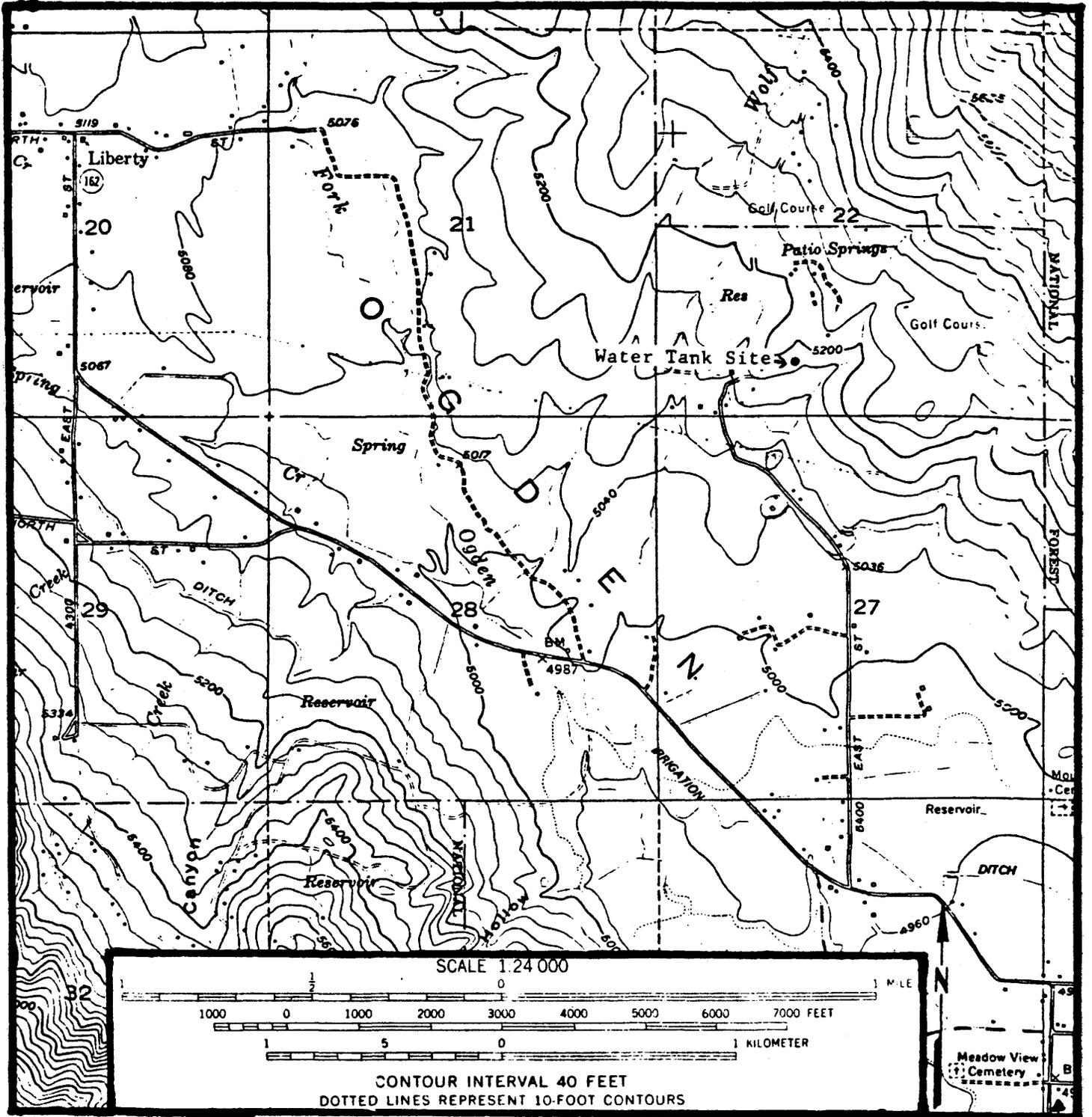
### Conclusions and Recommendations

In conclusion, the principle potential hazards affecting the site which should be considered in determining the suitability of the site for the proposed water tank are potential soil foundation problems, earthquake ground shaking, and possible deformation due to surface-fault rupture events. A site-specific soil foundation investigation should be conducted at the site to evaluate soil foundation characteristics and make recommendations concerning foundation design. As a minimum, construction should incorporate earthquake-resistant design required for UBC Seismic Zone 3, with inspection and monitoring by Weber County Building Inspectors as outlined for USSAC Seismic Zone U-4. Although hazards due to surface-fault rupture and landsliding are considered low, the County Geologist should be contacted to inspect the open excavation for the tank to confirm this.

### REFERENCES CITED

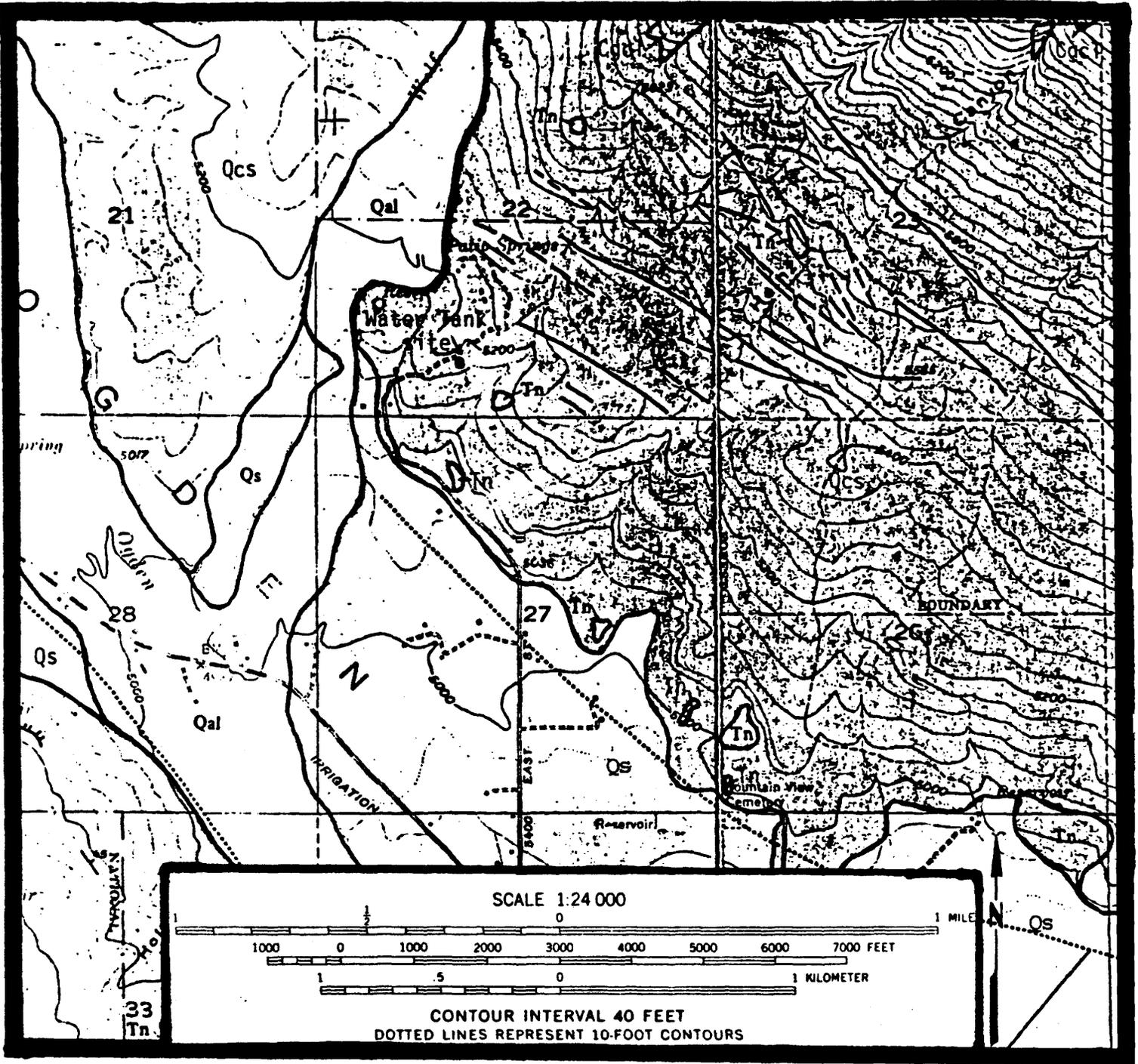
- Bucknam, R.C., Anderson, R.E., 1979, Estimation of fault-scarp ages from a scarp-height-slope-angle relationship: *Geology*, v. 7, p. 11-14.
- Chen and Associates, 1982, Investigation of escarpments, Wolf Star Condominium site, Wolf Creek Development, Weber County, Utah: Unpublished consultant's report, 9 p.

- Currey, D.R., and Oviatt, C.G., 1985, Durations, average rates, and probable causes of Lake Bonneville expansions, stillstands, and contractions during the last deep-lake cycle, 32,000 to 10,000 years ago, in Kay, P.A., and Diaz, J.F., eds., Problems of and prospects for predicting Great Salt Lake levels: Conference Proceedings, University of Utah Center for Public Affairs and Administration, Salt Lake City, Utah, p. 9-24.
- Doyuran, Vedat, 1972, Geology and ground water resources of Ogden Valley, Utah: University of Utah, Ph.D. thesis, Salt Lake City, Utah 134 p.
- Lofgren, B.H., 1955, Resume of Tertiary and Quaternary stratigraphy of Ogden Valley, in Eardley, A.J., ed., Tertiary and Quaternary geology of the Eastern Bonneville Basin: Utah Geological Society Guidebook to the Geology of Utah, no. 10, p. 70-84.
- Stewart, S.W., 1956, Gravity Survey of Ogden Valley, Weber County, Utah: University of Utah, M.S. thesis, Salt Lake City, Utah, 23 p.
- Sorensen, M.L., and Crittenden, M.D., Jr., 1979, Geologic map of the Huntsville Quadrangle, Weber and Cache Counties, Utah: U.S. Geological Survey Geological Quadrangle Map GQ-1503, 1:24,000 scale.
- Sullivan, J.T., Nelson, A.R., LaForge, R.C., Wood, C.K., and Hansen, R.A., 1986, Regional seismotectonic study for the Back Valleys of the Wasatch Mountains in northeastern Utah: U.S. Bureau of Reclamation, Seismotectonic Section, Division of Geology, Engineering and Research Center, Denver, Colorado, 317 p.
- Wallace, R.E., 1977, Profiles and ages of young fault scarps, northcentral Nevada: Geological Society of America Bulletin, v. 88, p. 1267-1281.



LOCATION MAP

Eden

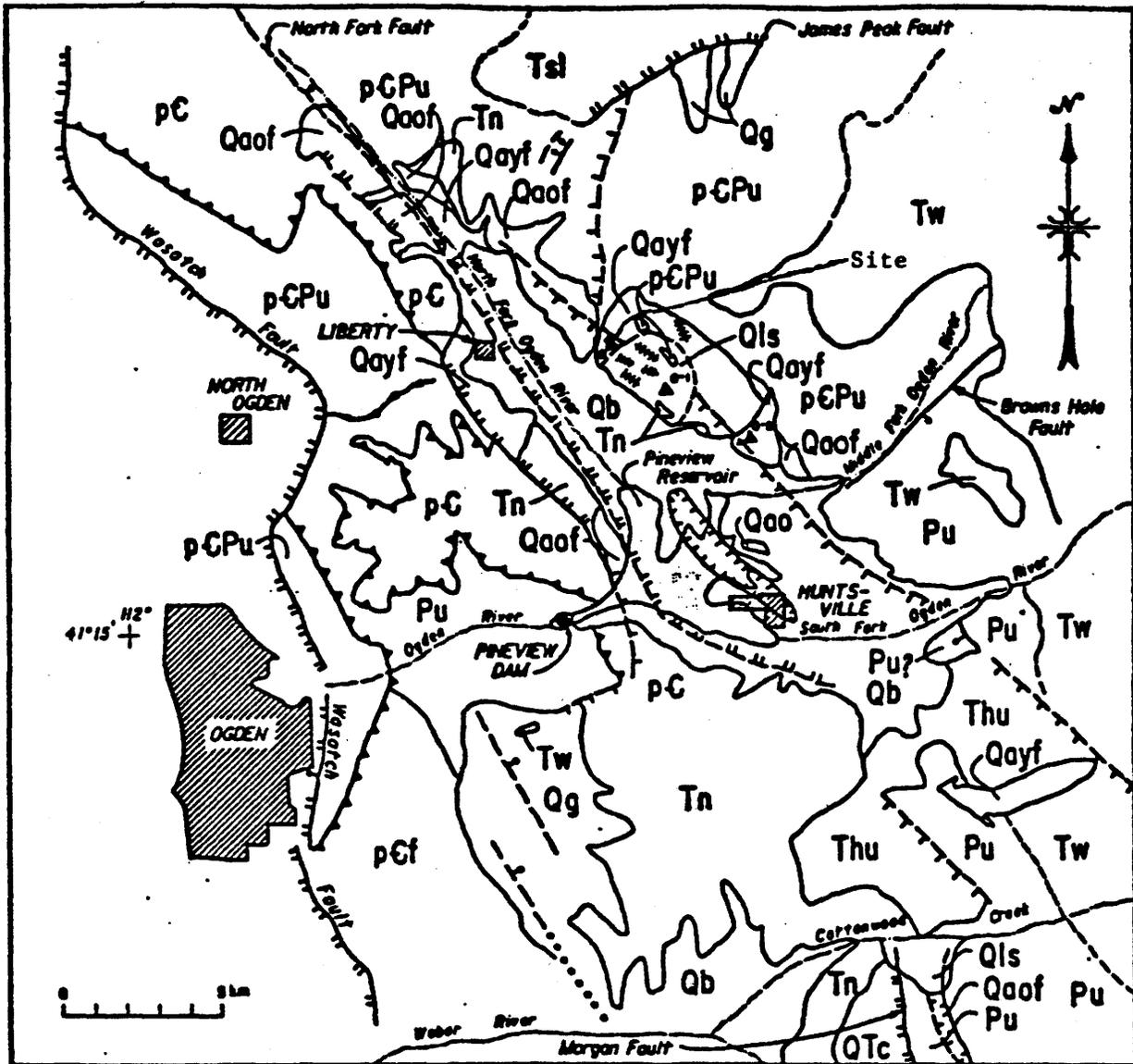


Explanation

- Qal = Holocene alluvial deposits, undifferentiated.
- Qcs = Holocene colluvium and slopewash.
- Qs = Pleistocene lacustrine silt deposits.
- Tn = Tertiary Norwood Tuff
- Egcl = Cambrian Geertsen Canyon Quartzite, lower member.
- Location of concealed faults, modified from Stewart (1958) = .....
- Fault scarps = \_\_\_\_\_
- Bonneville Shoreline = - - - - -

GEOLOGIC MAP

Source: Sorensen and Crittenden, 1979.



**EXPLANATION**

- Contact, dashed where approximately located.
- Late Quaternary normal faults, dashed where inferred or approximately located.
- Late Cenozoic normal faults, dashed where inferred or approximately located.
- Cenozoic normal faults, dashed where inferred or approximately located.
- Willard Thrust fault
- Ogden Thrust fault
- Eden water gap
- Maximum residual gravity anomaly from Stewart (1958)
- Lineaments (Sorenson and Crittenden, 1979)
- Streams
- Soil test pit

- QUATERNARY**
- Qayf Younger alluvial fan deposits.
  - Qb Lake Bonneville sediments and Holocene alluvium, includes post-Bonneville alluvium.
  - Qls Landslide.
  - Qoaf Older alluvial fan deposits.
  - Qoo Pre-Bonneville alluvium.
  - Qg Glacial deposits
- TERTIARY**
- Thu Pliocene? Huntsville fan glomerate.
  - Tsl Neogene Salt Lake formation.
  - Tn Late Eocene-Oligocene Norwood Tuff.
  - Tw Eocene Wasatch formation.
- PRE-TERTIARY**
- Pu Paleozoic undivided.
  - pCPu Paleozoic and Precambrian undivided.
  - pCf Precambrian Farmington Canyon Complex.
  - pE Precambrian in upperplate Willard Thrust, mostly Brigham Group.

Regional Geologic Map

Source: Sullivan and others, 1986.

SALT LAKE COUNTY

<b>Project:</b> Geoseismic Evaluation, Granite Fire Station Salt Lake County, Utah		<b>Requesting Agency:</b> Salt Lake County Fire Department	
<b>By:</b> Craig V. Nelson	<b>Date:</b> 8-25-87	<b>County:</b> Salt Lake County	<b>Job No.:</b> SL1
<b>USGS Quadrangle:</b> Draper			

## INTRODUCTION

The purpose of this report is to evaluate the geoseismic conditions of the proposed Granite Fire Station site and suggest guidelines for building design. The planned fire station will cover approximately 5,000 square feet, contain 2 or 3 bays, and house 6 personnel. The study was authorized by Mr. John Hiskey, S.L. County Director of Public Works, and undertaken at the request of Mr. Larry Hinman, Salt Lake County Fire Department Chief.

The site is located within Salt Lake County Planning Division's Surface Fault Rupture Special Study Area (Nelson, 1987a; fig. 1). The special study guidelines (fig. 2) recommend that a site-specific report addressing surface fault rupture hazards should be performed prior to construction of any essential facility, such as a fire station. Based on this, an initial appraisal of the site (Nelson, 1987b; appendix 1), and discussion with county personnel, it was determined that a detailed geoseismic study should be performed. The goals of the study were to locate and map all active faults passing through the site, determine the nature and history of faulting or other deformation, and recommend mitigation measures if necessary.

The scope of work consisted of an initial field reconnaissance, consultation with Public Works and Fire Department personnel, aerial photo interpretation, a subsurface investigation (trenching), and preparation of this report. The subsurface investigation consisted of an exploratory trench excavated in an east-west orientation (bearing: N 85° E) across the proposed building site perpendicular to the expected trend of faulting. Trenching was extended about 50 feet (15m) beyond the eastern and western edge of the proposed building location (fig. 3). The trench was 235 feet (71.5m) long and averaged 10 feet (3m) deep. A generalized graphical log of the south wall was constructed at a scale of 1:50 showing the stratigraphy exposed by the trench (fig. 4).

## SITE CONDITIONS

### General Description

The site occupies a 0.68 acre (0.275 hectare), triangular parcel of land located in the SE 1/4 NE 1/4 sec.11, T.3 S., R.1 E. Salt Lake Baseline and Meridian, (40° 34'20" North Latitude, 111° 47'48" West Longitude) in Salt Lake County, Utah (fig. 5). It is bounded to the east by Wasatch Boulevard, to the north by an abandoned access road to Wasatch Boulevard, and to the south and west by 9400 South (UT 209). Entrance is from 9400 South.

The elevation of the site is approximately 5180 feet (1580m) and has a

The elevation of the site is approximately 5180 feet (1580 m) and has a general slope of about 5 degrees to the east. Regional topography is shown in figure 5. Vegetation consists of clusters of thick oak brush with weeds and short grasses.

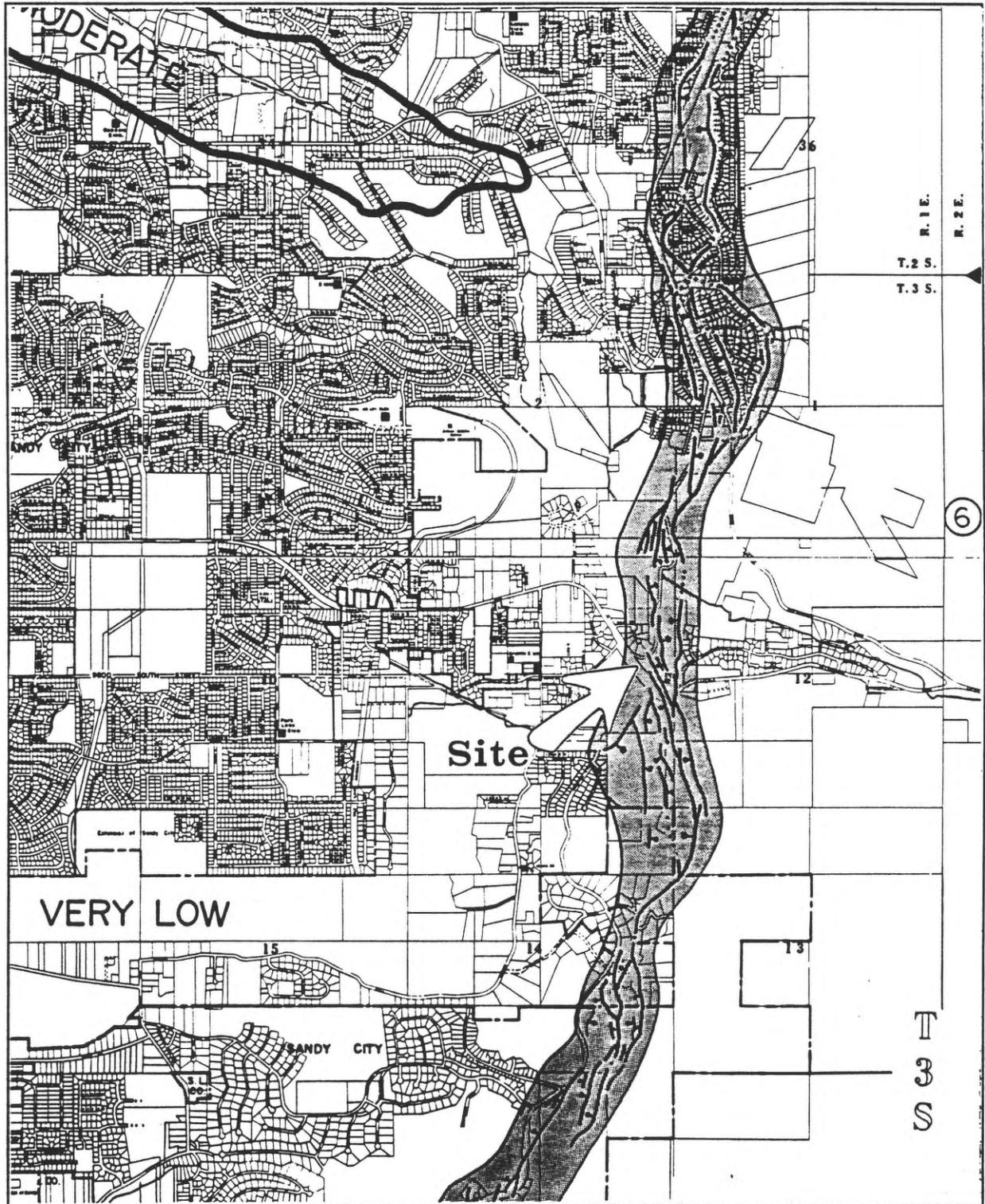


Figure 1. Surface Fault Rupture Special Study Area, see Figure 2 for explanation (Nelson, 1987a).

# SURFACE FAULT RUPTURE and LIQUEFACTION HAZARD AREAS

Compiled by  
 Craig V. Nelson, County Geologist  
 Salt Lake County Planning Division  
 August 1987  
 For more information call: 468-2061

This map is a compilation of the most recent geologic information available. It is for public information and general planning purposes only. This map does not substitute for site specific data obtained from special studies, and is subject to revision as new information becomes available.

### EXPLANATION



**FAULTS:** Solid line where location is known from scarps or trenching; dashed where approximately located or inferred; dotted where concealed. Bar and ball symbol indicates downthrown side.

**SURFACE FAULT RUPTURE SPECIAL STUDY AREA:** Indicates areas where site specific studies addressing fault rupture should be performed prior to construction.

#### LIQUEFACTION POTENTIAL:

HIGH  
 MODERATE  
 LOW  
 VERY LOW

> 50 %  
 50 - 10 %  
 10 - 5 %  
 < 5 %

Approximate probabilities that the critical ground acceleration needed to induce liquefaction will be exceeded in 100 years.

### Special Study Guidelines

Should a Site Specific Hazard Study Be Performed Prior to Construction?

Land Use (Facility)	Fault Study Area	Liquefaction Area			
		High	Mod	Low	V. Low
Essential Facilities (IBC 2312 (k)) & High Occupancy Buildings (IBC A-1, A-2, A-2.1)	YES	YES	YES	YES	YES
Industrial & Commercial Buildings (over 2 stories or 15,000 ft <sup>2</sup> )	YES	YES	YES	NO	NO
Multi-family Residential (4 or more units/acre) Other Ind. & Commercial	YES	YES	YES	NO	NO
Residential Subdivisions Residential-Single Lots & Multi-family developments (less than 4 units/acre)	YES	NO X	NO X	NO	NO
	NO X	NO X	NO X	NO	NO

X recommended disclosure to buyers/residents

### REFERENCES

- ANDERSON, L.R., KEATON, J.R., SPITZLEY, J.E., and ALLEN, R.C., 1985. Liquefaction potential map for Salt Lake County, Utah: Utah State University and Dames & Moore, final Report for U.S. Geological Survey Earthquake Hazards Reduction Program, Contract 814-02-0001-19910, map 1:48,000.
- CLUFF, L.S., BRIDAN, E.E., and GLASS, C.E., 1970. Wasatch fault, northern portion, earthquake fault investigation and evaluation: Woodward - Clyde & Associates, Oakland, CA, map 1:24,000.
- KEATON, J.R., CURREY, D.R., and BLIG, S.J., 1987. Paleoseismicity and earthquake hazards evaluation of the West Valley Fault Zone, Salt Lake urban area: in press, map 1:24,000.
- SCOTT, W.E., and SHROBB, R.R., 1985. Surficial geologic map of an area along the Wasatch fault zone in the Salt Lake Valley, Utah: U.S. Geological Survey Open-File Report 85-448, map 1:24,000.

Figure 2. Special Study Guidelines and Explanation (Nelson, 1987a).

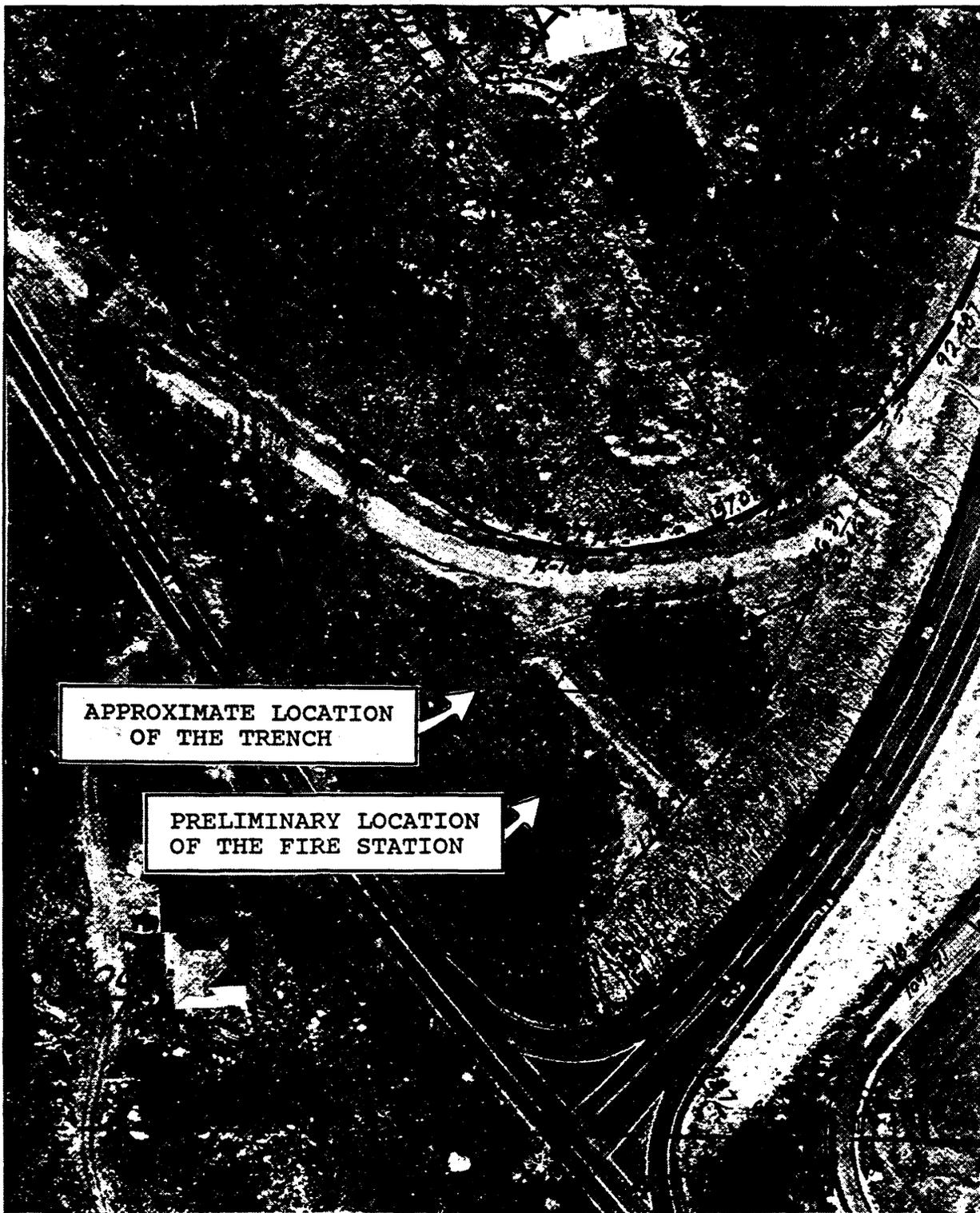
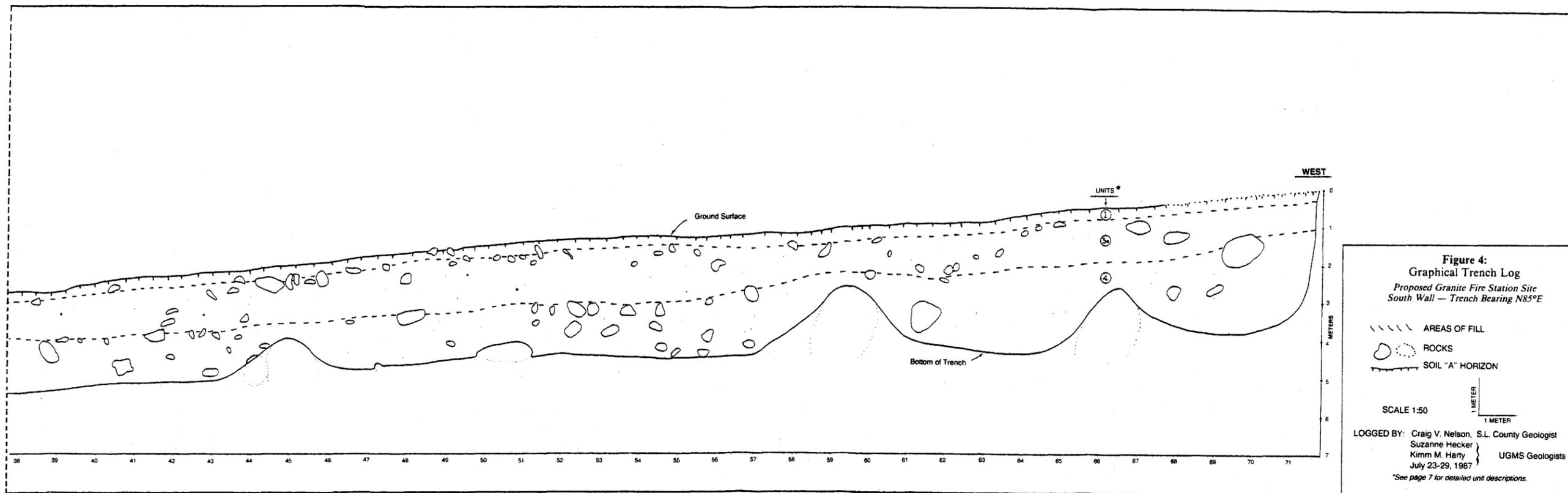
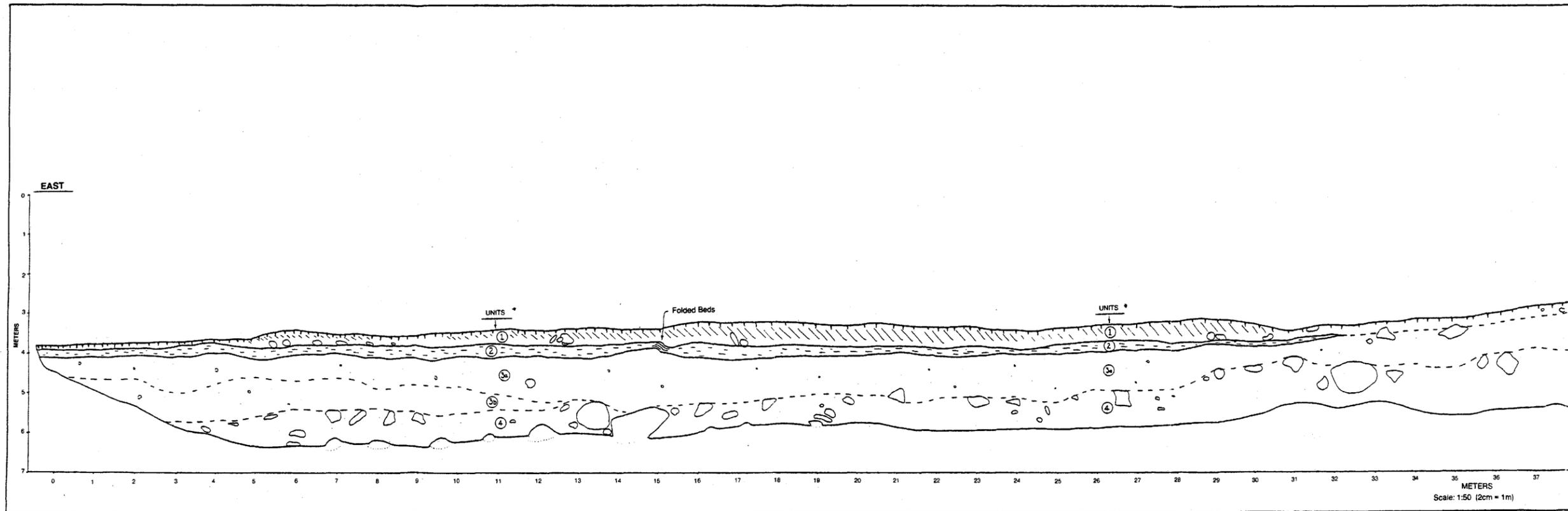


Figure 3. Proposed building location and exploratory trench orientation. The trench was extended 50 feet (15.2m) beyond the east and west edge of the structure (scale 1 inch = 100 feet).



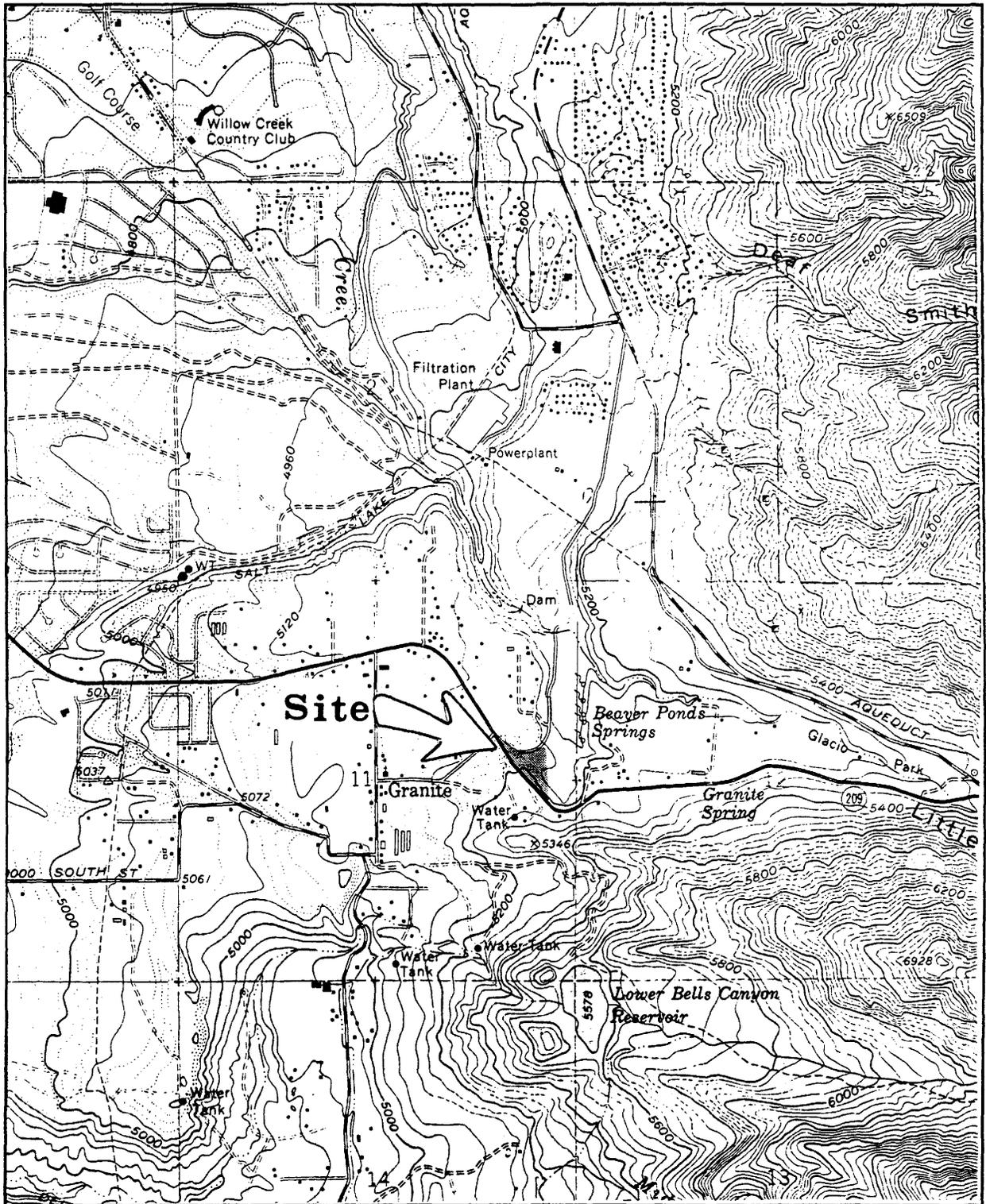


Figure 5. Location and topography of the proposed Fire Station Site (Draper Quadrangle).

## Surficial Geology

The site is underlain by Pinedale age (about 19,000 years old) glacial till deposited by glaciers from Little Cottonwood Canyon (Scott and Shroba, 1985; fig. 6). Boulders up to 6 feet (2m) are scattered across the site. The till exhibits a well-developed soil profile, and units observed in the trench (fig. 4) consisted of:

1: Sandy silt with gravel (ML); dark gray, organic-rich, poorly graded, numerous roots; soil A horizon (top soil) and localized areas of fill.

2: Clayey silt (MH); light gray, well sorted, thinly bedded (2-3mm) micaceous laminae, some undulation of bedding and areas of minor folding (soft sediment deformation?); appears to be water-deposited sediment, perhaps water impounded by a recessional moraine.

3a: Clayey gravel with cobbles (GC); dark gray, non-bedded, soil B horizon, some grussified quartz monzonite cobbles, a few burrows, gradational contact with unit 3b; weathered glacial till.

3b: Clayey gravel with cobbles (GC); red-brown, non-bedded, B soil better developed than in unit 3a, some grussified quartz monzonite clasts, gradational contact with unit 4; this unit was found only in the eastern part of the trench and may represent accelerated soil development caused by saturation from ponded water (unit 2); weathered glacial till.

4: Clayey gravel and boulders (GC); gray matrix-supported boulder to cobble gravel in sandy silt to silty sand matrix, very poorly sorted, quartz monzonite clasts up to 7 feet (2.5m) diameter; glacial till.

The Unified Soil Classification System (USCS) symbols are explained in appendix D. No Lake Bonneville deposits were observed at this location.

## EARTHQUAKE HAZARDS

The proposed site lies within the Intermountain Seismic Belt (fig. 7) on the Salt Lake segment of the Wasatch Fault (fig. 8), near the western edge of the fault zone. In this region the fault zone is a wide area (1200 feet; 366m) of complex branching faults. The Wasatch Front has been designated in the Uniform Building Code (UBC) as a Zone 3 seismic area, where "major damage" may result from an earthquake (Modified Mercalli Intensity VIII or higher, appendix C).

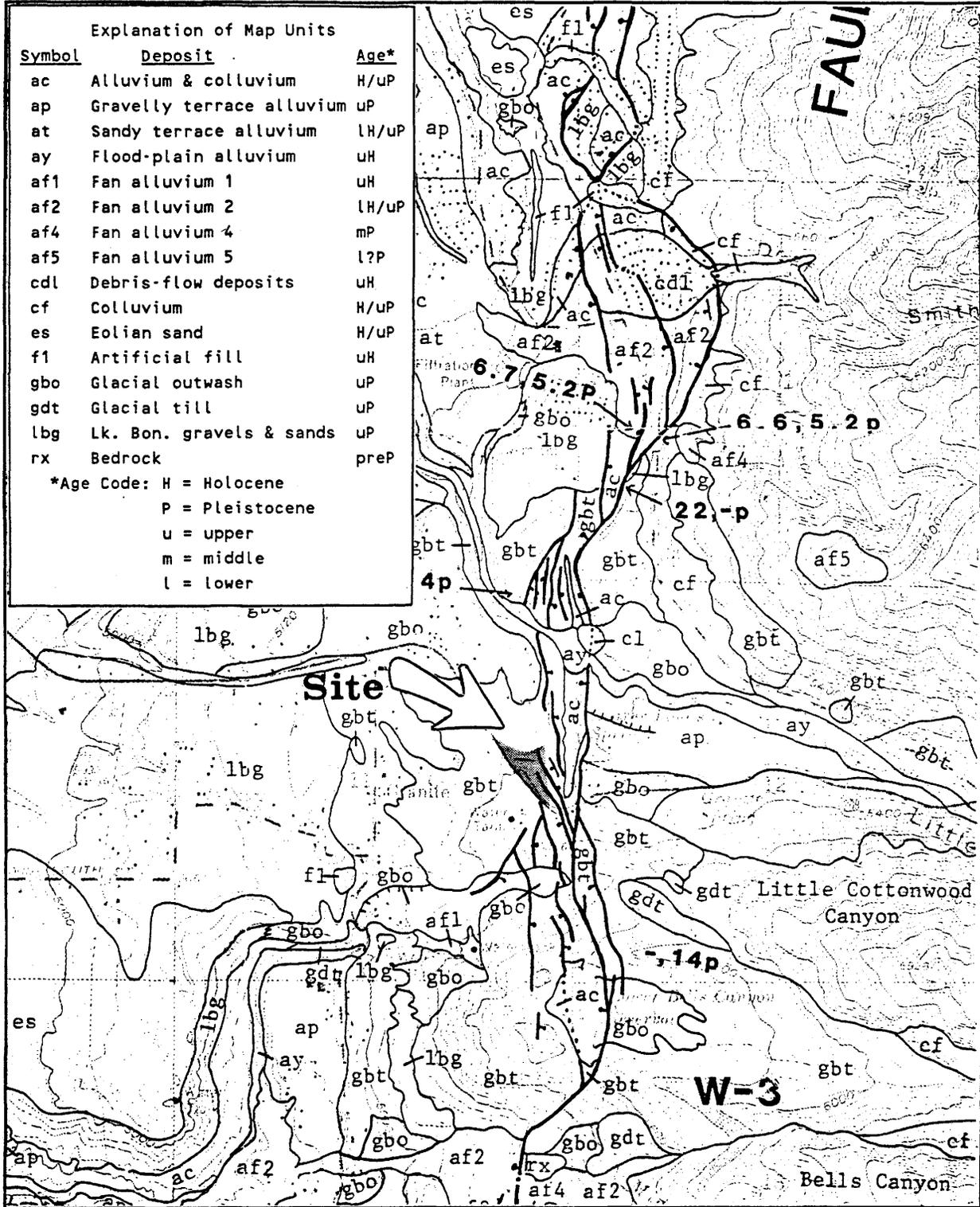


Figure 6. Surficial geologic map of the area around the proposed fire station site (Scott and Shroba, 1985).

# INTERMOUNTAIN SEISMIC BELT ~1850-1974

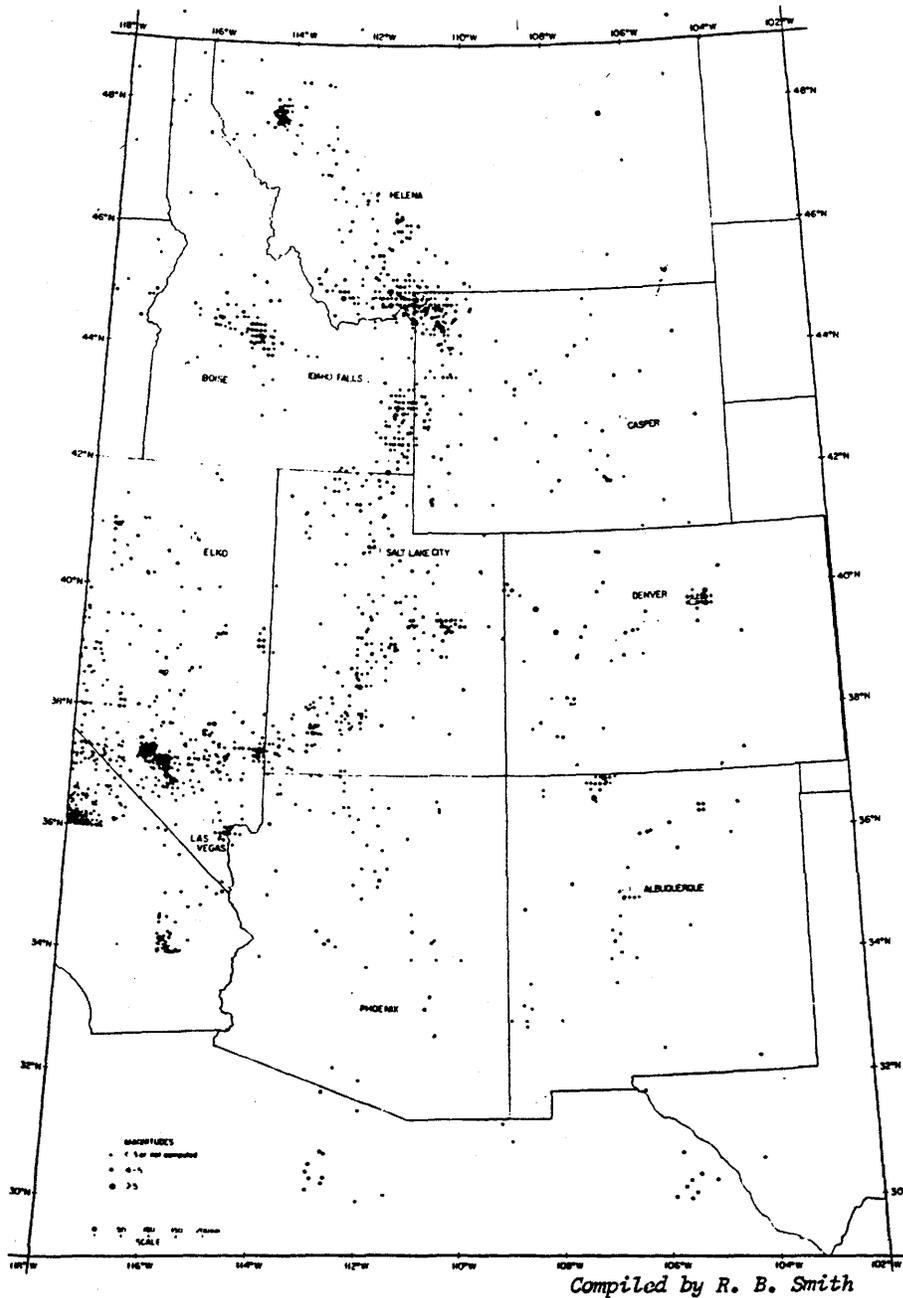


Figure 7. The Intermountain Seismic Belt, shown delineated by earthquake epicenters, extends from southern California, across the Wasatch Front, and into Montana (Arabasz and others, 1979).

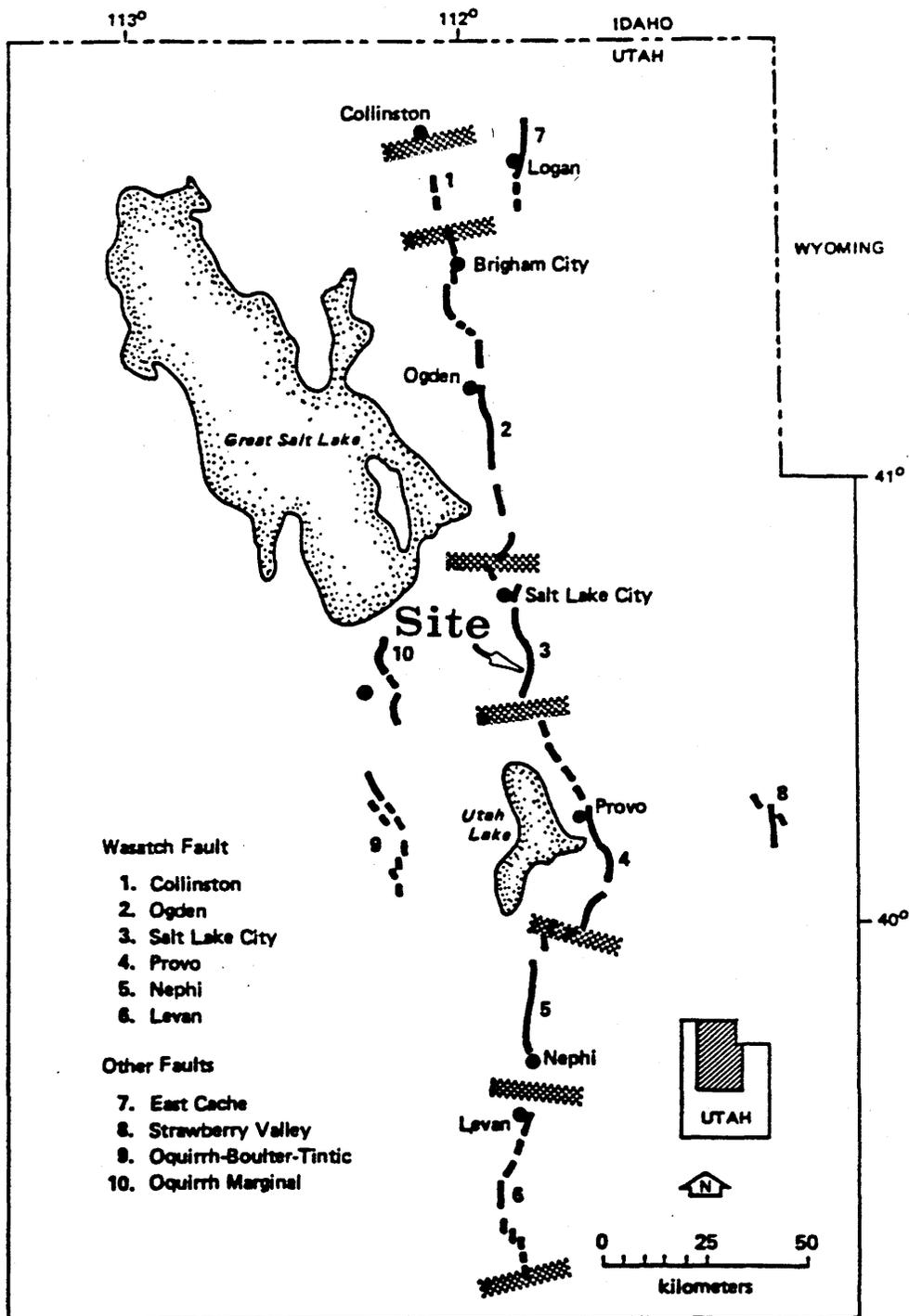


Figure 8. The segments of the Wasatch Fault. The site is located along the Salt Lake segment (Schwartz and Coppersmith, 1984).

## The Characteristic Earthquake

Although the populated area along the Wasatch Front has not experienced a large earthquake in historical time, geologic evidence indicates that there have been repeated large-magnitude seismic events over the past 10,000 years. Earthquakes are caused by strain slowly accumulating in the bedrock beneath the valley, and when the strength of the rock is exceeded, the rocks fail along faults. The stored strain is then suddenly released in the form of fault rupture and generation of seismic waves radiating out from the point of initial failure. Geologic studies along the fault zone have indicated that segments of the Wasatch Fault tend to generate large earthquakes of essentially similar size (the "characteristic" earthquake) repeatedly through time, followed by periods of quiescence (Schwartz and Coppersmith, 1984).

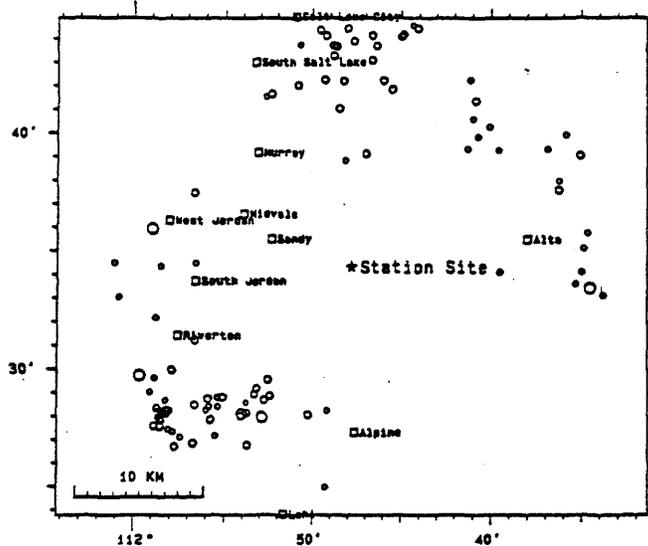
The characteristic earthquake (magnitude 7.0-7.5) for the Salt Lake segment occurs roughly every 2,400-3,000 years, causing the ground surface along major faults to be displaced 6-15.6 feet (2-4.75m), and producing other earthquake related hazards (see following sections). Doser and Smith (1982) suggest that 6.5 to 7.5 magnitude earthquakes in this area occur about 1,500 to 2,000 years. Timing for the last event is not well established, but in a recent fault study near Dry Creek, south of Bells Canyon, fault scarp diffusion modeling suggested an age of about 900 years and carbon-14 dating yielded a maximum age for the most recent event of about 1,890 years (Lund and Schwartz, 1987). The preferred average for all segments along the entire length of the Wasatch Fault suggests an average recurrence interval of 444 years, with the last major event about 300-500 years ago (Schwartz and Coppersmith, 1984).

Based on the available geologic data, the time since the last large earthquake is approaching the estimated recurrence period. Therefore, it is reasonable to suggest that a large seismic event may occur somewhere along the length of the Wasatch Fault during the expected life of the proposed fire station, and that it may occur along the Salt Lake segment.

No major and few minor earthquakes have occurred in this area within historical time (fig. 9; Arabasz and others, 1979). Seismic records from the University of Utah Seismograph Stations for a 12.4 mile (20 km) radius around the site are included in appendix B. The lack of seismicity in this area suggests strain is accumulating and not being released by small and moderate magnitude events.

### Surface Fault Rupture

Surface faulting has occurred in the area around the site, and large fault scarps representing the main trace and principal antithetic faults are found to the east (figs. 1 and 6). Based on mapping of scarps, Scott and Shroba (1985) indicate that no faults run directly through the site, but several trend in its direction and if projected northward, would pass through the site. Inspection using aerial photography of the area (1958 U.S.D.A. AAL 21V #15-17) confirmed the location of faults as shown in figures 1 and 6, and also suggested the presence of two lineaments of possible seismic origin passing through the site.



MAGNITUDES

- 0. +
- 1.0+
- 2.0+
- 3.0+

Figure 9. Earthquake epicenter plot for a 12.4 mile (20km) radius around fire station site. Data from 7/1/62 to 6/30/87 (U of U Seismograph Stations).

No evidence of major fault offsets were observed throughout the extent of the trench excavation. This indicates that surface fault rupture has not occurred during previous seismic episodes within the area traversed by the trench. The main surface rupture has been on the faults to the east. Data from the 1983 Borah Peak, Idaho earthquake suggests that ground rupturing tends to follow existing faults, created during previous earthquakes. Based on this evidence, it seems reasonable to conclude that in the future, the site may not be subject to large amounts of surface fault rupture. However, because of the coarse-grained, unstratified nature of the glacial till, evidence of ground cracks and smaller faults, with perhaps up to 6 inches (15cm) of displacement, may have been present, but not been observed.

### Ground Tilting

The ground surface of the site is sloping at about 5 degrees to the east, toward the mountains. The contacts between subsurface units also indicate back-tilting of the surface to the east into the fault zone. Typically, land near the

mountain front slopes into the valley, away from the mountains. The ground at the site appears to have been back-tilted by repeated movements on the major faults east of the property. In order to reconstruct the original orientation of the area (prior to tectonic deformation), an east-west topographic profile was constructed (fig. 10). Projections of ground surfaces above and below the zone of deformation suggest the site originally sloped 10-12 degrees to the west.

The glacial deposits at the surface of the site are estimated to be about 19,000 years old (Scott and Schroba, 1984). The amount of ground tilting during this time can be estimated by adding the back-tilted slope (5 degrees east) to the original surface slope (10-12 degrees west) to get 15-17 degrees total back-tilting over 19,000 years. Schwartz and Coppersmith (1984) suggest 7-8 major seismic events have occurred over this period, and this would imply that the site may be subject to 2-3 degrees of ground tilting during each event. However, it is not certain that this tilting occurred progressively with each earthquake, and it is possible that more or less than 2-3 degrees of tilting may accompany the next surface-faulting event.

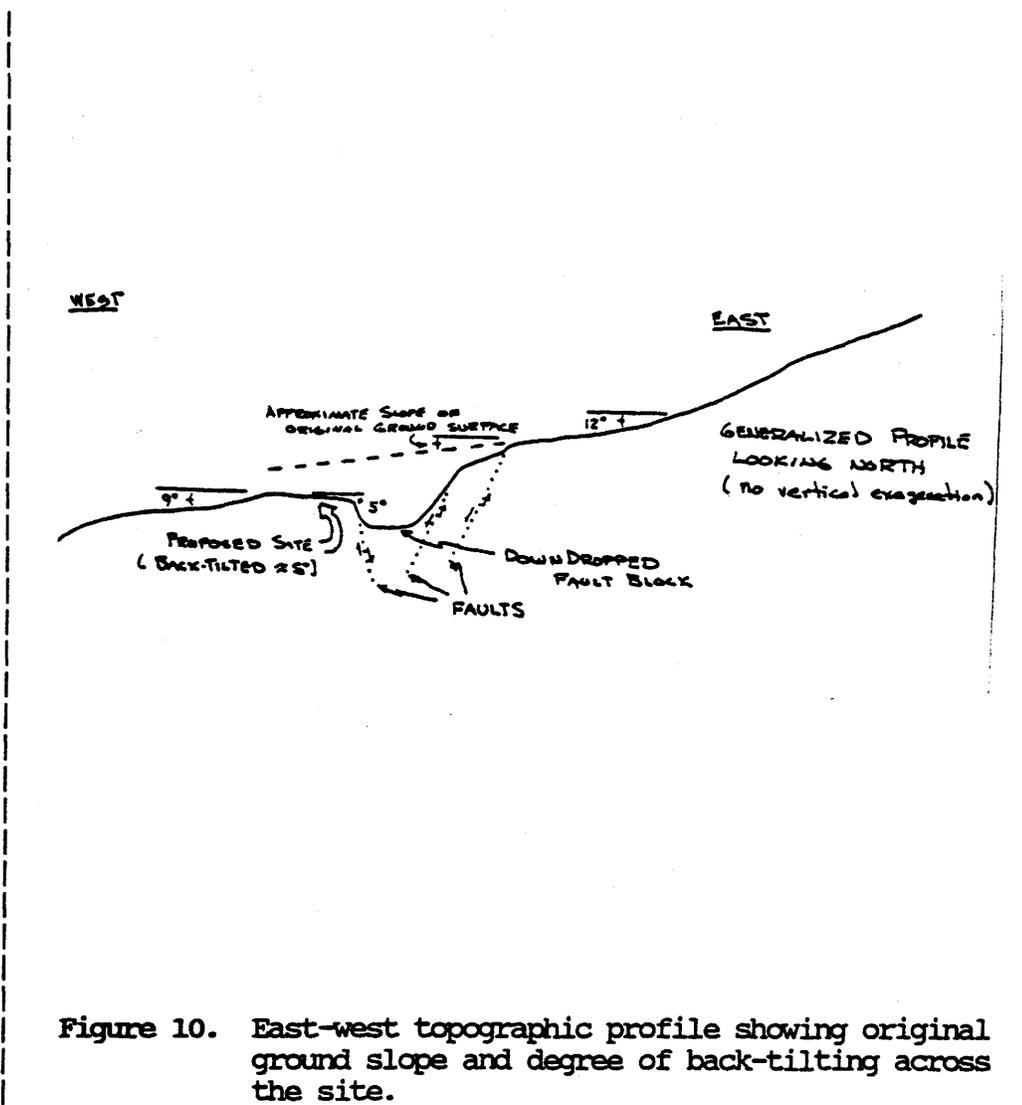


Figure 10. East-west topographic profile showing original ground slope and degree of back-tilting across the site.

## Ground Shaking

The most potentially damaging hazard during moderate to large earthquakes is ground shaking. The strongest ground shaking at the site would occur during an earthquake generated by rupture of the Salt Lake segment of the Wasatch Fault. However, there are also many other active faults throughout the region, including other segments of the Wasatch Fault, capable of generating seismic waves that may reach the site. Because these waves can be transmitted long distances, ground shaking is judged to be the most commonly occurring and greatest long-term seismic hazard.

It is critical that the fire station be designed to withstand expected levels of ground shaking without collapse so that the emergency equipment can function after a seismic event. Recommendations in the Uniform Building Code are based on expected levels of ground shaking in bedrock. Based on ground response data from seismic waves generated by nuclear blasts at the Nevada Test Site, Hays and King (1984) found that ground shaking in central valley areas may be amplified up to 10 times over that at bedrock sites. Their studies indicate that conditions in the site area will not greatly amplify ground shaking from distant earthquakes as is predicted further into the valley. Recent research, however, suggests that for closer earthquake epicenters, the ground shaking at sites near the fault rupture may be very severe (James Pechman, personal commun., August 11, 1987). The distance from the seismogenic rupture to the site becomes a critical factor in estimating ground response during rupture on the Salt Lake segment. A depth to seismogenic rupture of 1.2 miles (2km) on a fault dipping between 45 and 65 degrees yields distances between 1.3 and 1.7 miles (2.2 and 2.8km; K.W. Campbell, personal commun., August 24, 1987). For a zone within this distance from the seismogenic rupture, given a 7.5 magnitude earthquake along the Salt Lake segment, the peak ground acceleration is expected to be at least 0.6g, and perhaps over 1.0g, with peak horizontal velocities ranging from 55 to 150 cm/sec., and the duration of shaking may be up to 30 seconds (Campbell, 1987). This data suggests the UBC's minimum structural seismic lateral load parameters for Seismic Zone 3 may be insufficient at this site.

## Liquefaction

Another consequence of ground shaking is the loss of bearing strength of sediments, commonly due to liquefaction. Liquefaction occurs when ground-water saturated, fine-grained sediments (silt and fine sands) are subjected to ground shaking. As the ground accelerates, the fluid pore pressure between grains increases, tending to lessen the grain-to-grain contacts and allowing grains to slip past one another. In essence, liquefaction causes formerly solid ground to behave like a viscous liquid. This can have a disastrous effect on structures. Large buildings can roll-over, buried tanks and pipes can "float" to the surface, lateral spread landslides can occur in areas of only a few percent slope. The amount of ground acceleration needed to induce liquefaction is called the "critical acceleration" (Anderson and others, 1986).

The site lies in an area generally rated as having a "very low" liquefaction potential (Anderson and others, 1986). This means there is less than a 5 percent probability that the critical acceleration needed to induce liquefaction will be exceeded in 100 years.

## OTHER HAZARDS

### Flooding

The Flood Insurance Rate Map (FIRM) of the area (panel # 490102 0458B, Salt Lake County) indicates the site lies outside both the 100 and 500 year flood boundaries. Flooding due to dam failures was mapped by Case (1984) throughout Salt Lake County. This study assumed a "worst case" scenario, with simultaneous failure of all dams, as may occur during an earthquake, and streams at flood stage. The site lies outside both map's inundation areas, so the flooding potential at the site is rated as low.

### Slope Stability

No evidence of past slope instability was observed at or near the site during field and aerial photo reconnaissance. The gently sloping (5 degrees) ground surface is considered to be stable under static conditions. The site lies outside the potential debris flow hazard special study area (Nelson, 1987c). Any rock-fall hazard from the steep mountain front or nearby moraines will probably not impact the site, since the rocks will likely be caught in the graben or deflected by the road fill along Wasatch Boulevard or 9400 South. Overall, potential slope stability problems are rated as low.

### Radon

Radon (Rn-222) is a radioactive inert gas that has been associated with health problems, notably lung cancer. Radon gas is a decay product of the uranium (U-238) series, and originates in uranium-bearing rock formations, such as the Little Cottonwood Stock. Radon becomes a potential health problem when it is released from rocks and is rapidly transmitted through the soil, through cracked or porous foundations and basements, and into dwellings where it can be breathed. While it is not known for certain if a radon problem exists in the area, the site has been included in a potential radon hazard area (Sprinkel, 1987). Radon contamination may be avoided by properly sealing basements and foundations or using positive pressure ventilation.

## CONCLUSIONS and RECOMMENDATIONS

The proposed fire station site is located within the expected zone of deformation of the next surface faulting earthquake on the Salt Lake segment of the Wasatch Fault. Based on the most recent earthquake recurrence estimates, it is possible that the site area will be subjected to surface fault rupture, ground shaking, and ground tilting during the life of the structure.

If an emergency facility is built at this site, it is critical that it be designed and constructed to withstand expected seismic forces to insure survivability of the emergency equipment and personnel. In order to minimize the potential for ground displacements, it is recommended that the fire station be constructed as far to the west on the site as possible. A standard soil and foundation engineering study should be completed prior to foundation design and

the very low liquefaction potential rating should be confirmed during this investigation. A copy of this report should be made available to the county geologist. It is suggested that the structure's foundation be made impermeable to limit radon gas penetration, and alpha track etch cup monitors be installed after construction. It is also recommended the building be designed and constructed to withstand, without collapse:

- 1) small ground surface displacements (4-6 inches, 10-15cm)
- 2) 2-3 degrees of eastward tilting, and
- 3) a minimum lateral acceleration of 0.6g.

If the structure can be designed to withstand these seismic constraints without collapse and insure the availability of emergency equipment, this site may prove suitable for a fire station.

#### LIMITATIONS

The recommendations given in this report are based on the best information available at this time. Our understanding of seismic forces is not complete, and the actions of earthquakes, like most natural phenomena, cannot be predicted with precision. If new information becomes available, it is important the county geologist be contacted to reevaluate these recommendations.

#### ACKNOWLEDGEMENTS

Geological support during this study was furnished by Utah Geological and Mineral personnel in the form of trench logging assistance ( Bob Robison, Suzanne Hecker and Kimm M. Harty) and technical review (Gary E. Christenson). Earthquake records were furnished by Ethan D. Brown, senior staff seismologist with the University of Utah Seismograph Stations.

#### REFERENCES

- Anderson, L.R., Keaton, J.R., Spitzley, J.E., and Allen, A.C., 1986, Liquefaction potential map for Salt Lake County, Utah: Utah State University and Dames & Moore, Final Report for U.S. Geological Survey Earthquake Hazards Reduction Program, scale 1:48,000.
- Arabasz, W.J., Smith, R.B., and Richins, W.D. (editors), 1979, Earthquake studies in Utah, 1850 to 1978: University of Utah Seismograph Stations, Salt Lake City, 552 pp.
- Case, W.F., 1984, Dam failures in Salt Lake County, Utah, due to a local major earthquake: A worst-case scenario: Unpublished Utah Geological and Mineral Survey Report, scale 1:62,500.
- Doser, D.J., and Smith, R.B., 1982, Seismic moment rates in the Utah region: Bulletin of the Seismological Society of America, v. 72, no.2, p. 525-551.

- Hays, W.W., and King, K.W., 1984, The ground shaking hazard along the Wasatch Fault Zone, Utah: U.S. Geological Survey Open-File Report 84-763, p. 133-147.
- Lund, W.R., and Schwartz, D.P., 1987, Fault rupture and earthquake recurrence at the Dry Creek site, Salt Lake segment, Wasatch Fault Zone, Utah: Geological Society of America Abstracts with Programs, v. 19, no. 5, p. 317.
- Nelson, C.V., 1987a, Surface fault rupture and liquefaction hazard areas: Salt Lake County Planning Division, Salt Lake City, scale 1:37,000.
- , 1987b, Proposed granite fire station location: unpublished memorandum dated March 4.
- , 1987c, Debris flow and debris flood hazard areas: Salt Lake County Planning Division, Salt Lake City, scale 1:24,000, in preparation.
- Schwartz, D.P., and Coppersmith, K.J., 1984, Fault behavior and characteristic earthquakes: Examples from the Wasatch and San Andreas Fault Zones: Journal of Geophysical Research, v. 89, no. B7, p. 5681-5698.
- Scott, W.E., and Shroba, R.R., 1985, Surficial geologic map of an area along the Wasatch Fault Zone in the Salt Lake Valley, Utah: U.S. Geological Survey Open-File Report 85-448, 18 pp., scale 1:24,000.
- Sprinkel, D.A., 1987, Potential radon hazard map: Utah Geological and Mineral Survey Open-File Report 108, scale 1:1,030,000.

**APPENDIX A**

**Memorandum:**

**Proposed Granite Fire Station Location**

**March 4, 1987**



**SALT LAKE COUNTY PUBLIC WORKS DEPARTMENT**

**PLANNING DIVISION**  
2001 S STATE ST #N3700  
SALT LAKE CITY  
UTAH 84190-4200  
468-2061

COMMISSIONER  
DAVID M. 'DAVE' WATSON  
Director of Public Works  
JOHN D. HISKEY

March 4, 1987

DIVISION DIRECTOR  
CLAYNE J. RICKS

ASSOCIATE DIRECTOR  
of  
Public Works  
Romney M. Stewart  
488-5448

MEMORANDUM

ASSOCIATE DIRECTOR  
JEROLD H. BARNES

PLANNING  
DIVISION  
SECTIONS

Land Use  
Wm Marsh III  
Room 204  
488-5061

Plans & Research  
Jerold Barnes  
Room 204  
488-5061

Redevelopment  
Clair Hardman  
Room 204  
488-5061

Administration  
Room 204  
488-5061

To: Tom Sadler, S.L.Co. Fire Department  
From: Craig Nelson, S.L.Co. Geologist  
Subject: Proposed Granite Fire Station Location

In response to your request for recommendations concerning the geo-seismic setting of the proposed Granite Fire Station, I have reviewed geologic literature, examined air photography, and conducted a brief field reconnaissance of the site. The following recommendations summarize our meeting of March 2, 1987.

The proposed site lies within the Wasatch Fault Zone near the mouth of Little Cottonwood Canyon. Both U.S. Geological Survey geologists (Scott and Shroba, 1985) and private consultants (Cluff, Brogan, and Glass, 1970) have mapped the fault zone in this area as a complex of branching faults up to 1200 feet wide. Cluff and others' map shows two fault traces trending directly through the site. My air photo inspection (using 1958 coverage) confirms the presence of suspicious looking "lineaments" through the area.

Structures built straddling active Wasatch Fault segments can expect to suffer displacement during the next major surface rupturing earthquake. Research to date suggests:

1. The Salt Lake segment of the Wasatch Fault fails about every 2400-3000 (Schwartz and Coppersmith, 1984) years during a magnitude 7.1-7.3 event.
2. The most recent fault study (near Dry Creek, south of this site) suggested the last earthquake of this type occurred between about 900-1890 years ago.
3. It is expected that during the next surface faulting earthquake the total surface rupture across the fault zone will be between 6 and 15 feet. Although most of this displacement might occur along the

Tom Sadler, S.L. Co. Fire Dept.  
Re: Proposed Granite Fire  
Station Location

-2-

March 4, 1987

eastern portion of the fault zone, lesser ruptures can be expected along splay faults (buildings rarely survive surface displacements of greater than 1 foot).

Structures built within (or even adjacent) to the fault zone can also expect problems. Large blocks of earth, termed grabens, can be down dropped or severely tilted. Wasatch Boulevard lies on such a block between Big and Little Cottonwood Canyons. Tectonic subsidence, or back tilting toward the fault zone can also cause structural damage. During earthquakes it is also possible for landslides to occur on steeper slopes and impact buildings. Also, roads across the fault zone can be expected to be damaged and potentially impassable (particularly access to Little Cottonwood Canyon).

While it is possible to place an exploratory trench perpendicular to the fault traces, identify any faults, and avoid placing a structure directly across a known fault, many hazards (as previously mentioned) still exist within the fault zone. Based on these factors, I cannot recommend this site as suitable for construction of an emergency facility such as a fire station. I would recommend choosing a site further to the west, well away from expected zones of deformation, and I would be happy to assist you in finding a geologically satisfactory location.

Please contact me if you need further information or have any questions.

#### References

- Cluff, L.S., Brogan, G.E., and Glass, C.E., 1970, Wasatch Fault, northern portion, earthquake fault investigation and evaluation: unpublished consultant's report Woodward Clyde & Associates, Oakland, CA, 27p.
- Schwartz, D.P., and Coppersmith, K.J., 1984, Fault behavior and characteristic earthquakes: Examples from the Wasatch and San Andreas Fault Zones: Journal of Geophysical Research, Vol. 89, No. B7, pp. 5681-5698.

Tom Sadler, S. L. Co. Fire Dept.  
Re: Proposed Granite Fire  
Station Location

-3-

March 4, 1987

References

Scott, W.E., and Shroba, R.R., 1985, Surficial geologic map of an area along the Wasatch Fault Zone in the Salt Lake Valley, Utah: U.S. Geological Survey Open File Report 85-448, 18p.

cc: John Hiskey, Public Works  
Ken Jones, Development Services  
Clayne Ricks, Planning  
Roger Hillam, Real Estate

**APPENDIX B:**

**Earthquake Record of the Fire Station Area**

**July 1, 1962 through June 30, 1987**

## EARTHQUAKE DATA FOR THE UTAH REGION

(Explanation)

The following data are listed for each event:

1. Year (YR), date and origin time in Universal Coordinated Time (UTC). Subtract seven hours to convert to Mountain Standard Time (MST).
2. Earthquake location coordinates in degrees and minutes of north latitude (LAT-N) and west longitude (LONG-W), and depth in kilometers. "\*" indicates poor depth resolution: no recording station within 10 km or twice the depth.
3. MAG, computed local magnitude for each earthquake. "W" indicates Wood-Anderson records were used.
4. NO, number of P and S readings used in solution.
5. GAP, largest azimuthal separation in degrees between recording stations used in the solution.
6. DMN, epicentral distance in kilometers to the closest station.
7. RMS, root-mean-square error in seconds of the travel-time residuals:

$$\text{RMS} = \left[ \frac{\sum_i (W_i R_i)^2}{\sum_i (W_i)^2} \right]^{1/2}$$

where:

$R_i$  is the observed minus the computed arrival time for the  $i$ -th P or S reading,

$W_i$  is the relative weight given to the  $i$ -th P or S arrival time (0.0 for no weight through 1.0 for full weight).

Earthquakes 20 km from La Caille area

yr	date	orig	time	lat-n	long-w	depth	mag	no	gap	dmn	rms
62	906	305	41.19	40-35.94	111-58.94	7.0*	2.1	4	154	21	0.09
65	1122	1811	29.15	40-31.23	111-56.61	7.0*	1.7	5	133	28	0.23
69	922	1306	58.61	40-33.45	111-34.54	7.0*	2.0	5	150	32	0.58
69	1031	1314	24.45	40-41.35	111-40.86	7.0*	1.6	5	162	16	0.46
71	320	12	29.52	40-44.11	111-49.23	7.0*	1.2	5	139	3	0.35
71	320	2128	35.89	40-44.36	111-49.58	7.0*	1.5	6	137	3	0.07
71	407	2132	4.76	40-43.27	111-48.82	7.0*	1.3	4	134	5	0.43
71	616	2117	30.27	40-38.84	111-48.18	7.0*	0.7	4	117	8	0.24
71	727	1532	18.76	40-29.74	111-59.67	7.0*	2.5	6	138	21	0.10
71	727	1832	7.13	40-26.71	111-57.73	7.0*	1.5	5	160	22	0.18
72	103	230	3.13	40-41.03	111-48.50	7.0*	1.1	6	123	9	0.60
72	207	722	8.75	40-39.05	111-35.08	7.0*	1.5	8	141	17	0.75
72	401	715	23.12	40-37.47	111-56.64	7.0*	1.8	8	151	16	0.84
72	721	1247	19.67	40-42.22	111-45.98	7.0*	1.2	6	149	9	0.32
72	901	2030	25.98	40-42.03	111-50.82	7.0*	1.5	5	124	7	0.57
72	1004	2032	27.12	40-42.25	111-49.31	7.0*	1.2	4	134	7	0.11
73	629	2001	33.70	40-42.21	111-48.27	7.0*	1.8	5	131	7	0.51
73	1103	733	10.95	40-39.11	111-47.00	7.0*	1.0	6	168	8	0.28
74	214	1637	47.24	40-43.71	111-48.81	7.0*	1.2	6	202	4	0.24
74	1031	944	46.59	40-26.86	111-56.69	17.8	1.0	5	138	9	0.12
74	1101	2110	17.15	40-44.43	111-44.07	1.0	1.3	5	261	9	0.05
74	1118	6	23.81	40-27.16	111-55.48	1.9	0.1	6	138	7	0.23
74	1119	813	43.62	40-27.86	111-55.73	1.3	1.4	6	147	7	0.25
74	1209	1221	58.99	40-29.98	111-57.87	1.4	1.1	4	181	10	0.13
74	1209	1409	48.10	40-28.49	111-56.60	1.9	1.4	7	157	8	0.31
74	1220	2041	6.86	40-28.43	111-55.82	7.0*	0.3	3	171	7	0.
74	1225	748	18.43	40-39.33	111-41.29	7.0*	0.6	8	273	8	0.16
75	123	2139	29.21	40-43.69	111-46.34	1.3	1.4	14	96	6	0.28
75	310	1940	3.33	40-44.09	111-44.98	2.3	1.8	16	163	8	0.15
75	429	1945	56.59	40-43.08	111-46.62	0.1	1.4	12	140	7	0.23
75	513	2347	40.57	40-40.25	111-40.07	7.0*	0.7	8	281	9	0.15
75	711	1132	20.73	40-39.31	111-36.89	7.4	0.1	6	305	7	0.08
76	403	737	38.09	40-33.14	111-33.80	6.7	0.5	7	117	7	0.13
76	513	431	26.48	40-34.13	111-34.98	1.5	0.	7	237	17	0.30
76	513	434	58.70	40-33.63	111-35.35	7.1	0.1	7	233	17	0.19
76	521	2000	54.71	40-44.13	111-46.63	7.0*	1.4	14	98	26	0.27
76	716	1521	41.78	40-32.18	111-58.76	2.5	0.6	12	83	13	0.32
76	801	1621	26.30	40-27.83	111-58.43	8.8	0.2	10	89	11	0.18
76	808	922	12.86	40-28.25	111-58.03	1.8	1.0	11	74	10	0.17
76	809	655	40.03	40-28.69	111-58.24	5.9	0.7	12	82	10	0.29

Earthquakes 20 km from La Caille area

yr	date	orig	time	lat-n	long-w	depth	mag	no	gap	dmn	rms
76	811	30	21.86	40-28.16	111-58.26	6.5	0.2	6	159	10	0.11
76	811	100	43.06	40-28.08	111-58.16	6.3	0.9	11	85	10	0.15
76	812	134	54.34	40-28.28	111-58.15	6.7	0.6	12	74	10	0.15
76	812	2107	6.01	40-27.35	111-57.82	6.7	0.4	6	147	10	0.20
76	814	1433	6.56	40-28.25	111-58.33	4.9	-0.1	6	161	10	0.11
76	816	2106	8.60	40-28.18	111-58.39	10.3	0.5	5	160	10	0.09
76	823	750	59.24	40-27.91	111-58.54	6.6	1.3	13	91	10	0.11
76	823	755	18.09	40-27.45	111-58.07	6.9	0.4	8	91	10	0.16
76	825	22	3.02	40-29.04	111-59.09	9.0	-0.3	7	175	10	0.11
76	919	2107	58.18	40-27.99	111-58.64	8.6	0.1	7	159	10	0.12
76	920	343	43.12	40-29.63	111-58.84	5.9	-0.5	5	181	11	0.02
76	920	647	57.45	40-28.04	111-58.49	8.6	-0.4	6	159	11	0.10
76	1008	2216	16.89	40-34.11	111-39.50	2.2	0.4	11	89	8	0.24
76	1125	1934	49.46	40-27.95	111-58.65	7.5	0.1	5	158	10	0.14
76	1125	1938	23.48	40-28.42	111-58.68	5.6	0.	5	165	11	0.12
76	1126	1018	26.44	40-28.36	111-58.68	1.0	1.0	9	86	10	0.11
76	1209	1820	59.06	40-28.25	111-49.14	7.6	0.6	9	83	2	0.24
77	205	2345	16.53	40-29.56	111-52.54	1.3	1.7	6	151	3	0.09
77	208	1910	55.92	40-28.06	111-50.21	5.0	1.7	6	100	1	0.19
77	402	1005	50.97	40-27.61	111-58.86	8.4	1.7	12	153	10	0.15
77	402	2100	59.36	40-27.58	111-58.53	6.7	1.0	9	81	10	0.18
77	1207	2108	47.98	40-43.89	111-47.67	1.1	1.2	13	89	5	0.25
78	207	32	12.19	40-27.11	111-57.40	7.0*	0.9	4	285	9	0.36
78	207	2145	32.64	40-33.05	112- 0.82	9.7	0.5	16	93	13	0.15
78	208	18	35.84	40-34.50	112- 1.07	3.5	0.3	8	134	16	0.42
78	225	1616	26.14	40-44.44	111-48.03	1.2	1.7	8	117	4	0.21
78	621	1705	50.73	40-37.97	111-36.23	6.8	0.2	10	69	14	0.16
78	1118	1813	13.52	40-26.77	111-53.73	3.7	1.0	13	173	17	0.33
79	303	2247	16.05	40-28.15	111-53.73	3.1	1.7	21	118	4	0.25
79	327	2104	19.59	40-27.96	111-52.86	1.0	2.0	14	64	3	0.27
79	406	103	31.64	40-28.95	111-53.32	0.8	1.5	13	75	3	0.26
79	420	1619	38.92	40-29.18	111-53.19	0.1	1.5	15	114	3	0.36
79	427	35	27.83	40-28.69	111-52.75	1.1	1.2	12	115	2	0.37
79	512	1706	58.32	40-28.26	111-55.97	9.2	0.4	8	152	7	0.29
79	512	2138	51.82	40-28.40	111-55.33	7.1	0.6	13	79	6	0.23
79	514	118	43.55	40-28.75	111-55.88	9.1	1.3	15	79	7	0.25
79	514	438	2.45	40-28.81	111-55.36	8.8	0.9	12	120	6	0.25
79	515	848	6.18	40-28.81	111-55.09	3.7	1.3	15	78	6	0.38
79	606	9	9.47	40-28.58	111-53.80	3.3	0.7	8	87	15	0.27
79	623	100	51.52	40-28.87	111-52.42	3.4	1.3	14	74	2	0.32

Earthquakes 20 km from La Caille area

yr	date	orig	time	lat-n	long-w	depth	mag	no	gap	dimn	rms
79	718	2146	5.94	40-28.02	111-54.09	1.0	1.3	12	91	5	0.29
79	1117	2220	53.41	40-24.96	111-49.26	7.0*	0.1	6	143	24	0.30
80	815	2211	26.86	40-28.10	111-54.03	0.3	2.0	16	78	16	0.30
80	919	45	37.11	40-37.59	111-36.26	7.7	1.0	10	116	14	0.20
80	1120	2035	38.54	40-44.18	111-44.88	1.4	1.7	10	197	17	0.31
80	1202	2242	48.93	40-34.36	111-58.50	3.5	0.4	17	128	17	0.29
81	1209	1836	34.92	40-43.66	111-48.63	7.1	1.0	14	114	5	0.42
82	321	656	10.26	40-35.13	111-34.87	1.7	0.5	11	86	11	0.21
82	321	705	14.04	40-35.79	111-34.64	1.9	0.3	9	116	10	0.29
83	517	2022	17.63	40-41.66	111-52.34	7.4	1.0	11	153	11	0.41
83	801	1604	33.44	40-40.59	111-40.98	1.9	0.8	11	105	13	0.25
83	929	2039	3.12	40-28.29	111-58.19	6.5	1.3	22	66	10	0.30
83	1117	1955	6.07	40-43.74	111-50.66	3.8	0.8	9	199	6	0.14
84	618	1155	42.06	40-41.84	111-45.49	3.0	1.2	17	69	10	0.31
84	704	202	59.79	40-39.26	111-39.59	2.3	0.8	8	127	12	0.14
84	714	847	9.97	40-39.84	111-40.70	1.8	0.7	13	82	12	0.33
85	311	732	55.31	40-34.48	111-56.55	2.1	1.0	18	71	15	0.25
85	729	1437	43.69	40-41.54	111-52.68	1.7	0.5	12	124	11	0.27
86	428	633	49.39	40-44.56	111-44.35	2.8	0.4	14	103	7	0.27
86	1126	2246	27.02	40-42.25	111-41.13	4.9	0.5	8	86	10	0.18
87	106	1957	53.54	40-39.92	111-35.86	5.5	0.6	12	75	14	0.10

number of earthquakes = 101

\* indicates poor depth control

W indicates Wood-Anderson data used for magnitude calculation

**APPENDIX C:**

**The Modified Mercalli Intensity Scale of 1931**

**MODIFIED MERCALLI INTENSITY SCALE OF 1931**  
**(Abridged)**

- I. Not felt except by a very few under especially favorable circumstances.
- II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
- III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.
- IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls made cracking sound. Sensation like heavy truck striking building; standing motor cars rocked noticeably.
- V. Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop.
- VI. Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.
- VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.
- VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Disturbed persons driving motor cars.
- IX. Damage considerable in specially designed structures; well designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.
- X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.
- XI. Few, if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
- XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

Source: Earthquake Information Bulletin; 6 (5), 1974, p. 28.

**APPENDIX D:**

**The Unified Soil Classification System**

Unified Soil Classification System.

MAJOR DIVISIONS		GROUP SYMBOLS	TYPICAL NAMES		
COARSE-GRAINED SOILS More than 50% retained on No. 200 sieve*	GRAVELS 50% or more of coarse fraction retained on No. 4 sieve	CLEAN GRAVELS	GW Well-graded gravels and gravel-sand mixtures, little or no fines		
		GRAVELS WITH FINES	GP Poorly graded gravels and gravel-sand mixtures, little or no fines		
			GM Silty gravels, gravel-sand-silt mixtures		
			GC Clayey gravels, gravel-sand-clay mixtures		
	SANDS More than 50% of coarse fraction passes No. 4 sieve	CLEAN SANDS	SW Well-graded sands and gravelly sands, little or no fines		
			SP Poorly graded sands and gravelly sands, little or no fines		
		SANDS WITH FINES	SM Silty sands, sand-silt mixtures		
			SC Clayey sands, sand-clay mixtures		
			FINE-GRAINED SOILS 50% or more passes No. 200 sieve*	SILTS AND CLAYS Liquid limit 50% or less	ML Inorganic silts, very fine sands, rock flour, silty or clayey fine sands
					CL Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
OL Organic silts and organic silty clays of low plasticity					
SILTS AND CLAYS Liquid limit greater than 50%	MH Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts				
	CH Inorganic clays of high plasticity, fat clays				
	OH Organic clays of medium to high plasticity				
HIGHLY ORGANIC SOILS	PT Peat, muck, and other highly organic soils				

\* Based on the material passing the 3-in. (75-mm) sieve.

Project: Dresden Lane Fault Investigation		Requesting Agency: Salt Lake City Planners	
By: Craig V. Nelson	Date: 1-24-86	County: Salt Lake	Job No.: SL2
USGS Quadrangle: Fort Douglas			

## INTRODUCTION

As requested in a previous memorandum (Nelson, 1986), Delta Geotechnical Consultants conducted a fault investigation study at the site of the proposed Dresden Lane apartment complex at approximately 550 South 900 East, Salt Lake City, Utah. Trench investigations were conducted January 15-17, 1986. The purpose of this memorandum is to document observations made during site visits pending release of the consultants report.

Two trenches were excavated generally perpendicular to the trend of the fault plane (fig. 1). Due to the consultant's perceived potential liability problems each trench was backfilled at the end of the day. This time constraint did not allow time for proper detailed geotechnical logging, only simplified unscaled sketches of one trench wall were made. Only one trench was opened each day, which eliminated the direct comparison of exposures between trenches. The use of a large backhoe capable of trenching in excess of 5 meters proved valuable when dealing with areas of relatively deep fill.

## TRENCH EXPOSURES

### Trench A

Trench "A" (fig. 2A) revealed one fault with bedded gravels and cobbles on the upthrown block and fine-grained lake sediments on the down thrown block. The actual fault plane was poorly defined in this trench, being contained in a deformed zone 30-45 cm in width. The lake sediments showed evidence of drag folding down to the west. Due to the disturbed nature of the upper meter of sediment (fill) a complete stratigraphic sequence was not available in either trench. Initially this exposure was interpreted as a very old scarp with onlapping lake sediments, but based on the features in trench "B" this interpretation was revised. This again indicates the utility of having all trenches open simultaneously. This trench confirmed the location of one fault but did not intersect the eastern fault indicated in Delta's 1984 report.

### Trench B

Trench "B" (fig. 2B) was excavated across earlier trenches but at depths up to about 4 m. This trench revealed three faults: an eastern fault in bedded gravel and cobbles, a western fault separating the bedded gravel and cobbles from fine-grained lake sediments, and a fault across the gravel/cobble unit about 1.5 meters east of the west fault. The west fault is considered to be correlative to the fault exposed in trench "A". Trench "A" probably did not extend eastward far

fault exposed in trench "A". Trench "A" probably did not extend eastward far enough to expose the two other faults. Significant drag folding was present in the lake sediments in a down to the west fashion. No distortion or fracturing was noted in the lake sediment unit other than minor (a few cm) offset beds. The west fault was in a zone of deformation similar to that noted in trench "A".

University of Utah professor Don Currey was present during inspection of trench "B" to aid in interpretation of the stratigraphy. Dr. Currey believes the gravel/cobble unit represents pre-Bonneville alluvial fan deposits. The fine-grained unit represents Lake Bonneville deposition beginning with a thin layer of clean, well sorted gravel (initial transgression beach deposits), through shallow water and into deep lake deposits. A red, poorly sorted, cobble and gravel unit was exposed below the transgressive gravel layer in the downthrown fault block. Dr. Currey interprets this unit as pre-Bonneville isotope stage IV deposits. I concur with Dr. Currey's observations.

#### FAULTING

##### Displacement

Because units could not be correlated across the west fault the apparent minimum displacement must be greater than the trenching depth (about 3 meters). Given the preferred average for faulting on the Salt Lake fault segment of 2 meters, it is reasonable to conclude there is more than one seismic event represented by this fault.

The middle fault cut beds in the gravel/cobble unit. Distinct beds could be correlated across this fault, resulting in an apparent displacement down to the west of about 45 cm. It is my opinion this fault is a secondary feature related to movement on the west fault, similar to the drag effect exhibited in the lake sediments but in the more brittle manner expected in coarse-grained deposits.

The gravel/cobble bedding is poorly defined across the eastern fault making correlation difficult. It is believed that no units correlate across the fault, yielding an apparent minimum displacement of 2+ meters. This fault could also represent more than one faulting event.

##### Timing

Dating the last movement on any of the faults is difficult. The upper stratigraphy has been removed or disturbed, destroying any evidence from soil or overlying units. Lacking firm data one must rely on circumstantial evidence to get an estimate of most recent movement.

The most recent unit observed cut by the west fault is the deep lake sediment unit, which is probably of Bonneville shoreline age. This would place the maximum faulting date at about 15,000 y.b.p. Because of the plastic deformation of the drag folding in the lake sediments, it might be postulated that these sediments were saturated when folding occurred. If saturation was due to Lake Bonneville water, the lake would have to have been at or above the site elevation (about 4250'). This would correspond to the Gilbert shoreline level and place faulting at about 10,500 y.b.p. If faulting were to occur in unsaturated fine-grained sediments one would expect to see many small adjustment faults common in a brittle

deformation event. This approximate dating also applies to the middle fault since it appears to have been caused during a common event.

Dating the east fault is the most difficult. This fault cuts pre-Bonneville deposits that have a minimum age of about 20,000 y.b.p. A minimum age for most recent faulting might be estimated based on the amount of calcium carbonate filling fractures along the disturbed fault plane, but I can only say that this fault does not look "fresh", and can not venture any type of minimum date.

#### SUMMARY

From trench investigations, three faults have been found crossing the site of the proposed Dresden Place Apartment Complex. Two of the three faults appear to have experienced movement in more than one seismic event. An approximate date bracket for two of the faults is proposed at between 15,000 and 10,500 y.b.p. No timing parameters are estimated for the third fault due to lack of evidence.

#### SELECTED REFERENCES

- Delta Geotechnical Consultants, Inc., 1984, Geotechnical study, proposed Vantage apartment development, 550 South 1000 East, November 6, 1984, 11 p.
- 1985, Fault study at the proposed Dresden Lane Apartments, 550 South 900 East, Salt Lake City, Utah: unpublished consultant's report, December 16, 1986, 6 p.
- Nelson, C.V., 1986, Review of Delta Geotechnical Consultant's report for Dresden Lane Apartment Project, 550 South 900 East, Salt Lake City: unpublished memorandum, dated January 7, 1986, 5 p.
- Schwartz, D.P., and Coppersmith, K.J., 1984, Fault behavior and characteristic earthquakes: examples from the Wasatch and San Andreas Fault Zones: Journal of Geophysical Research, v. 89, no. B7, p. 5681-5698.

UTAH COUNTY

Project: Preliminary geologic hazard investigation for the Emergency Services Storage buildings		Requesting Agency: Utah County Emergency Services	
By: Robert M. Robison	Date: December 1987	County: Utah	Job No.: U1
USGS Quadrangle: Orem, Pelican Point			

This report is in response to a request from the Utah County Emergency Management Services to perform a preliminary geologic hazards evaluation for the storage buildings owned by Utah County located in the NW 1/4 of the NW 1/4 of Sections 5, T. 6 S., R. 2 E., SLB&M (fig. 1). The scope of the investigation included a review of pertinent literature, aerial photography interpretation, and site reconnaissance. The Utah County facilities are located on fine-grained, laminated Lake Bonneville bottom deposits. Slope is very gentle, under 5%, and vegetation consists mostly of ground cover.

Probably the most potentially damaging geologic hazard is earthquake ground shaking. Rogers and others (1984) indicate site conditions in this area may amplify ground shaking from 3.7 to 6.2 times that of bedrock (fig. 2), at least for seismic waves with vibrational frequencies of 0.2 to 0.7 seconds. These waves are particularly destructive to buildings 3 to 7 stories. The actual response of the building to ground shaking would depend on the engineering design and construction, as well as site geology.

Anderson and others (1986) include the site in an area of high liquefaction potential. The rating is based on the proximity of the ground-water table and the type of sediments at the site. A high rating means that the probability during a 100-year period for liquefaction to occur is >50% (Anderson and others, 1986). The effect of liquefaction at this location would probably be a loss of bearing strength under the foundation. The effects of liquefaction on the building may be cracking of the floors and/or foundation, or possibly tilting of the structure, depending on the type of building response and the severity and extent of the liquefaction.

The site is located within one mile of the shoreline of Utah Lake. In 1984, the lake reached a maximum flood elevation of 449 feet, but dredging projects along the Jordan River have greatly reduced the possibility of inundation such that it is not expected to exceed 4493 feet. If Deer Creek dam were to fail catastrophically, the water level in Utah Lake would raise only about 8 inches (Case, 1985), which, at the present lake level (4486.24 as of Oct. 20, 1987, Howard Denny, Utah County Engineers office, personal communication), flooding would probably not seriously affect the County storage facilities which are at about 4497 feet elevation (estimated from 7 1/2 minute topographic map). It is possible that seicheing related to earthquake ground shaking may reach this elevation, particularly if tilting of the basin occurs, but data are insufficient to evaluate this phenomenon.

No known faults have been mapped through the site. The nearest trace of the Wasatch fault zone is about 3 1/2 miles to the east (fig. 3). Dustin and Merritt (1980) make reference to faults in the site. However, surface fault rupture along

the Wasatch fault could indirectly affect the site due to downdropping and tilting of the basin toward the mountains causing a shift in Utah Lake to the east (fig. 3, Smith and Richins, 1984). Keaton (1986) indicates that if this were to occur at the same magnitude as that of the 1959 Hebgen Lake earthquake the area around the county buildings may experience ponded water.

None of the hazards present are sufficiently serious to preclude use of the site for storage. The principal factor to be considered is the possibility of building collapse accompanying ground shaking, and an analysis of the compliance of the structure to present seismic building codes may be advisable if explosive or hazardous materials or materials of great value or critical importance during an earthquake are to be stored there. Because the site is in a flat area 4 miles from the mountain front, the landslide, debris flow, and rock fall hazards are very low.

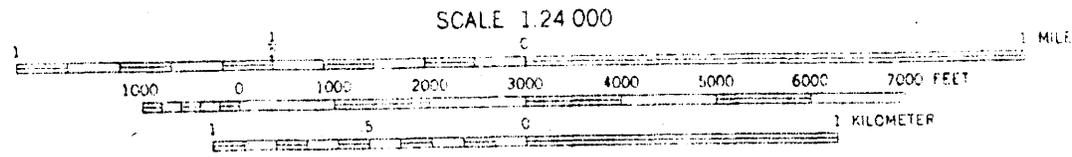
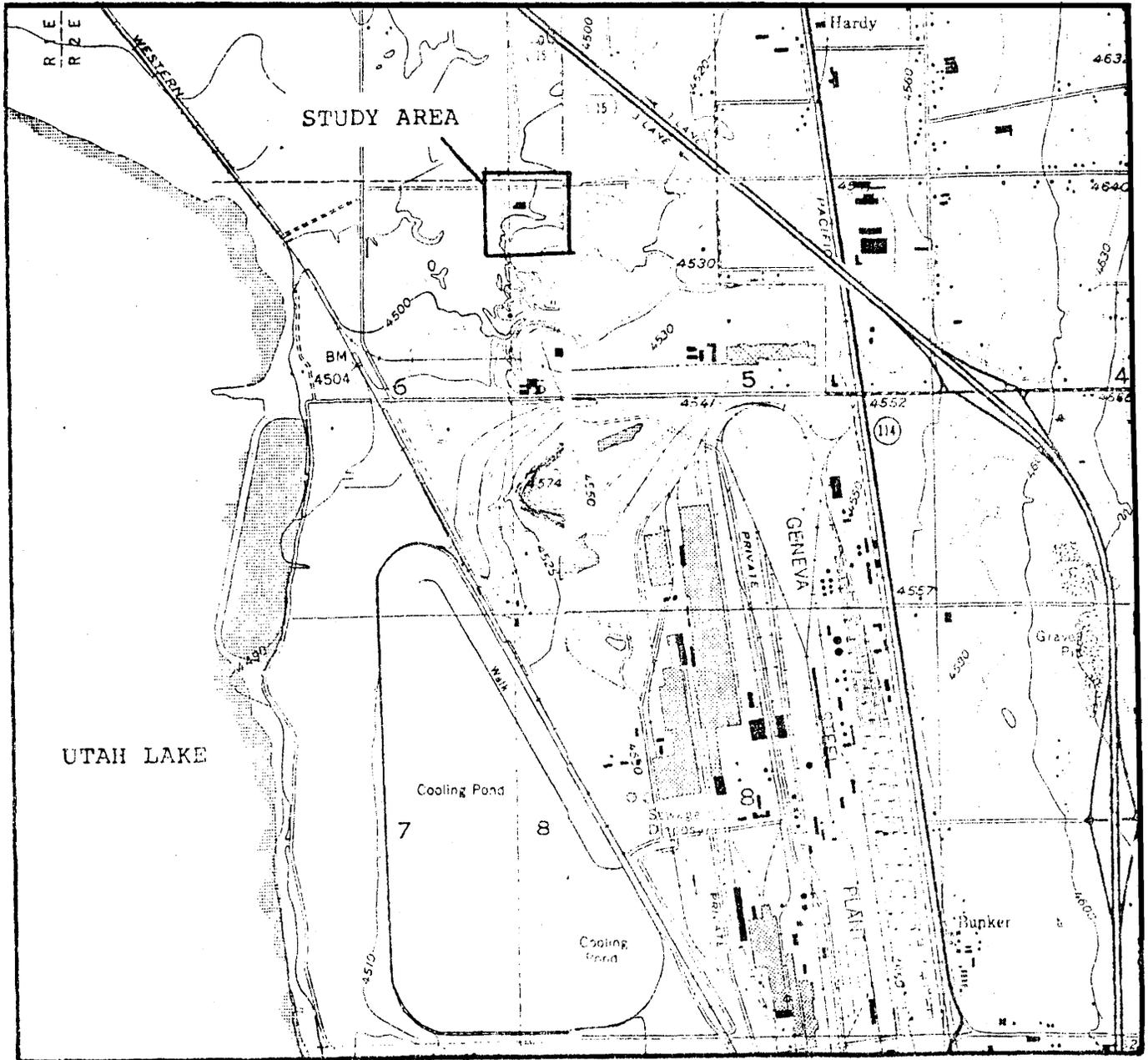


Figure 1. Map showing the location of the Utah County emergency services storage buildings.

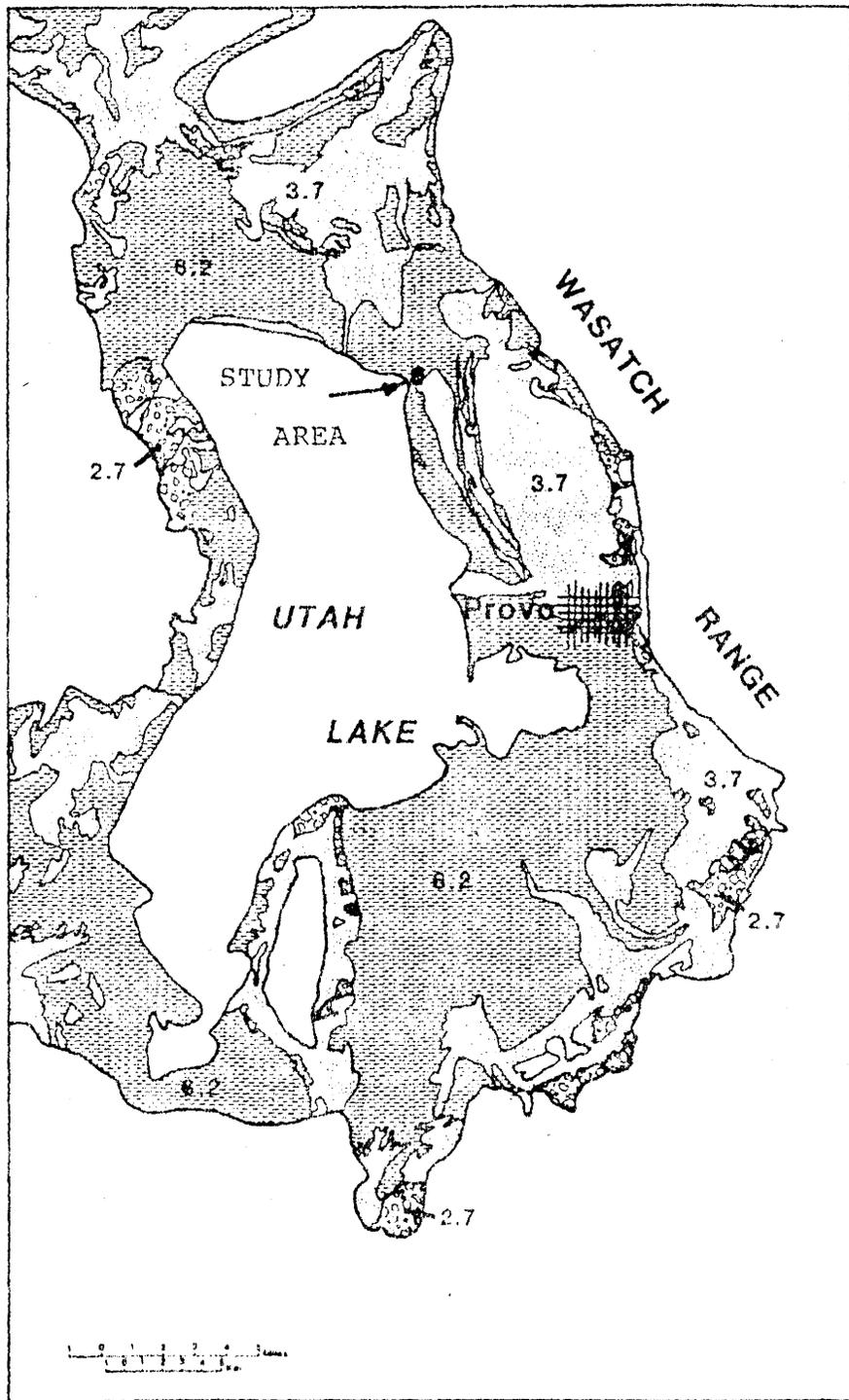


Figure 2. Map showing the relative ground shaking in response to a theoretical earthquake. The numbers indicate average (mean) response of the ground relative to locations in bedrock. Adapted from Rogers and others (1984).

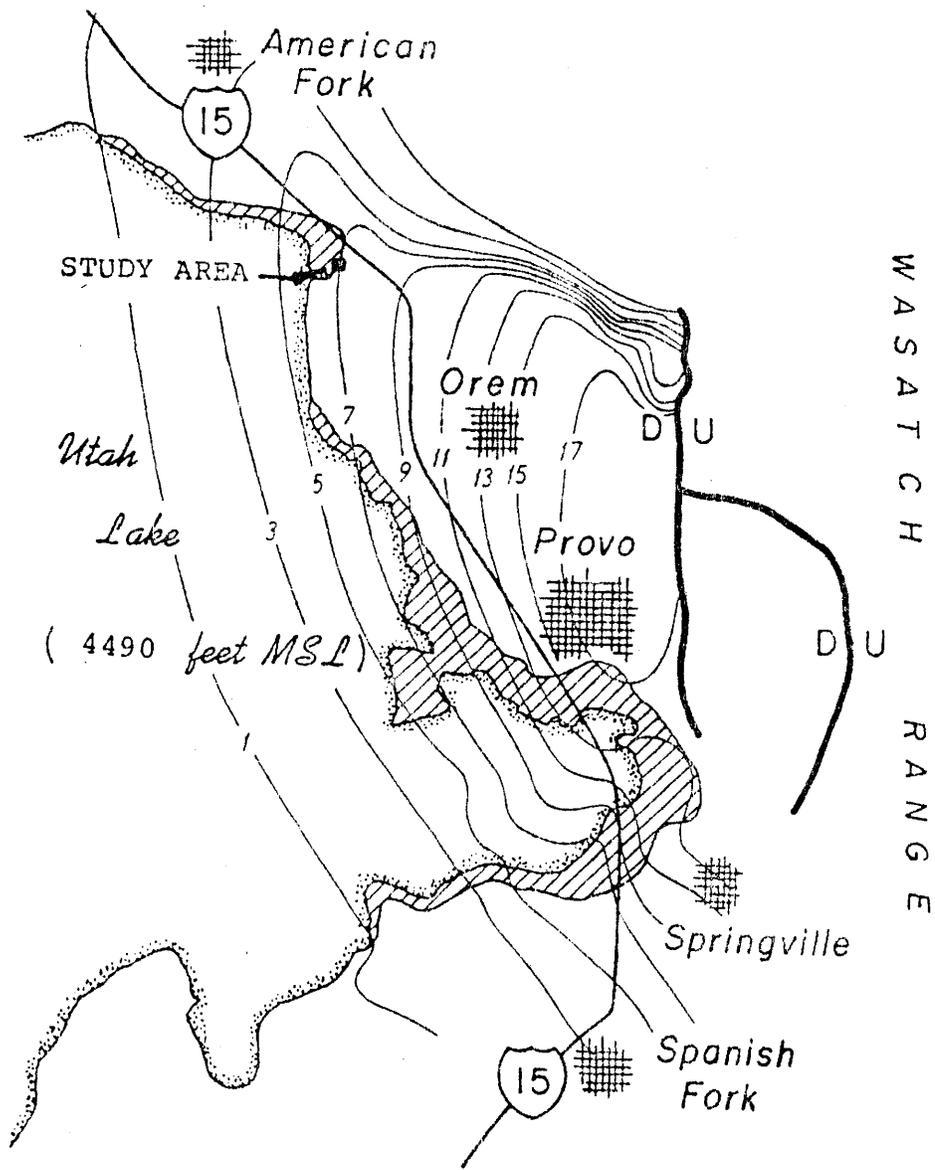


Figure 3. Map showing the Wasatch Fault zone in relation to the study area. Faults are depicted as the heavy black lines. The down-dropped side is designated with a "D" and "U" is on the up-thrown side. Thinner lines with numbers indicate, in feet, the possible seismic tilt if an earthquake with the same deformation as the 1959 Hebgen Lake event were to occur. Adapted from Smith and Richins (1984).

<b>Project:</b> Geologic hazards in the Payson City golf course area		<b>Requesting Agency:</b> Payson City	
<b>By:</b> Robert M. Robison	<b>Date:</b> March 12, 1987	<b>County:</b> Utah	<b>Job No.:</b> U2
<b>USGS Quadrangle:</b> Spanish Fork			

This report is in response to a request from Lorene Ellsworth, Planning and Zoning Administrator for Payson City, to evaluate the geologic hazards in the vicinity of the newly proposed Payson City golf course. The site is located in Sections 22, 23, 26, and 27, T. 9 S., R. 2 E., SLB&M (fig 1). The scope of the investigation included a review of pertinent literature and aerial photos, and a field reconnaissance conducted on March 3, 1987.

Geologic maps of the area have been prepared by Davis (1983) and Bissel (1963). The site is underlain by Lake Bonneville beach deposits and pre-Bonneville alluvial-fan material. Tithing Mountain, which is on the west side of the study area, is composed of Paleozoic limestone locally covered by this deposits of alluvium/colluvium with small post-Bonneville alluvial fans at the mouths of intermittent drainages.

Utah County is in an earthquake hazard area, and the site would be subjected to strong ground shaking from a moderate or large earthquake within Utah or Juab Valley or from large earthquakes outside the area. Ground shaking in the unconsolidated deposits at the site may be amplified 2.7 to 3.7 times that in nearby bedrock (Rogers and others, 1984).

Another hazard accompanying earthquakes is surface fault rupture along pre-existing fault scarps. Several fault scarps have been mapped mainly along the eastern margin of Rocky Ridge (Cluff and others, 1973), but none of the scarps extend into the area designated for the golf course. Preliminary maps by Machette (1986, personal commun.) show faults to the west; none are located within the golf course areas.

Flood Insurance Rate Maps (FIRMS) indicate that the area is not in the 100- or 500-year flood plain and that only minimal flooding is expected. However, the Goose Nest area is a closed depression; and if development were to make the enclosure impermeable, drainage water may pond. Ground water is expected at depths below 50 feet, and the potential for liquefaction is very low (Anderson and others, 1986).

A small active landslide was noted in the SW 1/4 of Section 2, T. 9 S., R. 2 E., SLB&M. This slide was apparently in alluvium/colluvium covering a slope which exceeds 30%. Downslope soil creep was also noted on several steep slopes. No large landslides occur in the immediate area of the golf course, but large slides exist about 1 mile south of the site. These slides are in the Paleozoic Manning Canyon Shale and the Cretaceous-Tertiary rocks, primarily the North Horn Formation. The Manning Canyon Shale has caused slides in Provo City and Provo Canyon, and the North Horn Formation is responsible for the Thistle Slide.

The Soil Conservation Service (Swenson, 1972) has mapped soils within the study area which have severe limitations for foundations for low buildings because of high shrink-swell potential and/or restrictive slopes.

#### CONCLUSIONS AND RECOMMENDATIONS

No geologic conditions exist which would preclude construction in the area, but several hazards must be considered. Slopes in excess of 30% should be avoided to help mitigate landslides and erosion. Care should be taken to control grading and cut slopes as outlined in the Uniform Building Code (UBC). Soil foundation investigations should be performed prior to construction particularly in the zones of high shrink/swell potential outlined by the SCS (Swenson, 1972). Although no recent fault scarps were mapped in the area, it is possible that faults with no surface expression may exist, and the local building officials should watch for evidence in excavations and inform the County Geologist if any faults are found. If development should proceed toward the south, an additional geologic hazard investigation should be conducted to delineate areas of severe landslide potential.

#### SELECTED REFERENCES

- Anderson, L.R., Keaton, J.R., and Bischoff, J.E., 1986, Liquefaction potential map for Utah County, Utah: Utah State University and Dames and Moore unpublished report for the U.S. Geological Survey, 46 p.
- Bissel, H.J., 1963, Lake Bonneville: Geology of southern Utah Valley, Utah: U.S. Geological Survey Professional Paper 257-B, 130 p.
- Cluff, L.S., Brogan, G.E., and Glass, C.E., 1973, Wasatch fault, southern portion; Earthquake fault investigation and evaluation; unpublished report prepared for the Utah Geological and Mineral Survey by Woodward-Lundgren and Associates, Oakland, California, 79 p.
- Davis, F.D., 1983, Geologic map of the southern Wasatch Front, Utah: Utah Geological and Mineral Survey Map 55-A, scale 1:100,000.
- Rogers, A.M., Carver, D.L., Hays, W.W., King, K.W., and Miller, R.D., 1984, Preliminary estimates of geographic variation in relative ground shaking in the Wasatch Front Urban Corridor: U.S. Geological Survey Open-File report 84-763, p. 547-556.
- Swenson, J.L., and others, 1972, Soil survey of Utah County, Utah: United States Department of Agriculture, Soil Conservation Service, in cooperation with Utah Agricultural Experiment Station, 161 p.

<b>Project:</b> A review of geologic hazards for a proposed water tank for Mapleton City, Utah		<b>Requesting Agency:</b> Mapleton City	
<b>By:</b> Robert M. Robison	<b>Date:</b> January 1988	<b>County:</b> Utah	<b>Job No.:</b> U3
<b>USGS Quadrangle:</b> Spanish Fork Peak			

## INTRODUCTION

This report is in response to a request from Marjorie Stokes, administrative assistant for Mapleton City, to conduct a geologic hazards review for a proposed water tank for Mapleton City. Rollins, Brown, and Gunnell, Inc., of Provo, Utah is the engineering firm hired to develop the site. The tank will have a 1 million gallon capacity and will be buried 24 feet with the top of the tank at 4920 feet elevation. The site selected for the tank is in the N 1/2 of the NE 1/4 of Section 27, T. 1 S., R. 3 E., SLB&M (fig. 1). The scope of this investigation consisted of a site visit, review of pertinent literature, and aerial photographic mapping.

## GEOLOGY

The site is located in Utah Valley along the east boundary of the Basin and Range province at the base of the Wasatch Range. Utah Valley is a down-dropped fault block separated from the Wasatch Range by the Wasatch fault zone (WFZ). The mountain to the east which rises abruptly from the trace of the WFZ is composed of Paleozoic age Oquirrh limestone.

The material at the site consist of Lake Bonneville silt and clay (Mike Machette, unpublished mapping, 1987; Davis, 1983), and is probably a remnant of a delta deposited in Lake Bonneville by the Spanish Fork River. The sediments were most likely deposited at the time the lake was near its highstand about 15,000 to 16,000 years ago. The deposits are light-colored, laminated, and well-drained. The soils support grazing type vegetation and some field crops.

## GEOLOGIC HAZARDS

### Earthquakes

Ground-shaking is probably the greatest geologic threat to the area. Utah Valley is located within the Intermountain Seismic Belt (ISB) which is a zone of diffuse seismicity which extends from southern Nevada northward to central Montana and includes the Wasatch Front. Also, ground shaking will occur at this site even if the earthquake is centered on one of the other nearby segments of the WFZ. Youngs and others (1987) reports that ground acceleration has a 10% probability of exceeding 0.70 g within a 250 year period.

Surface fault rupture is probably not a hazard at this site because the nearest mapped trace of the Wasatch Fault is over 1/2 mile east (fig. 10). Two small north-south trending parallel scarps were noted west of the site about 500 feet, which have

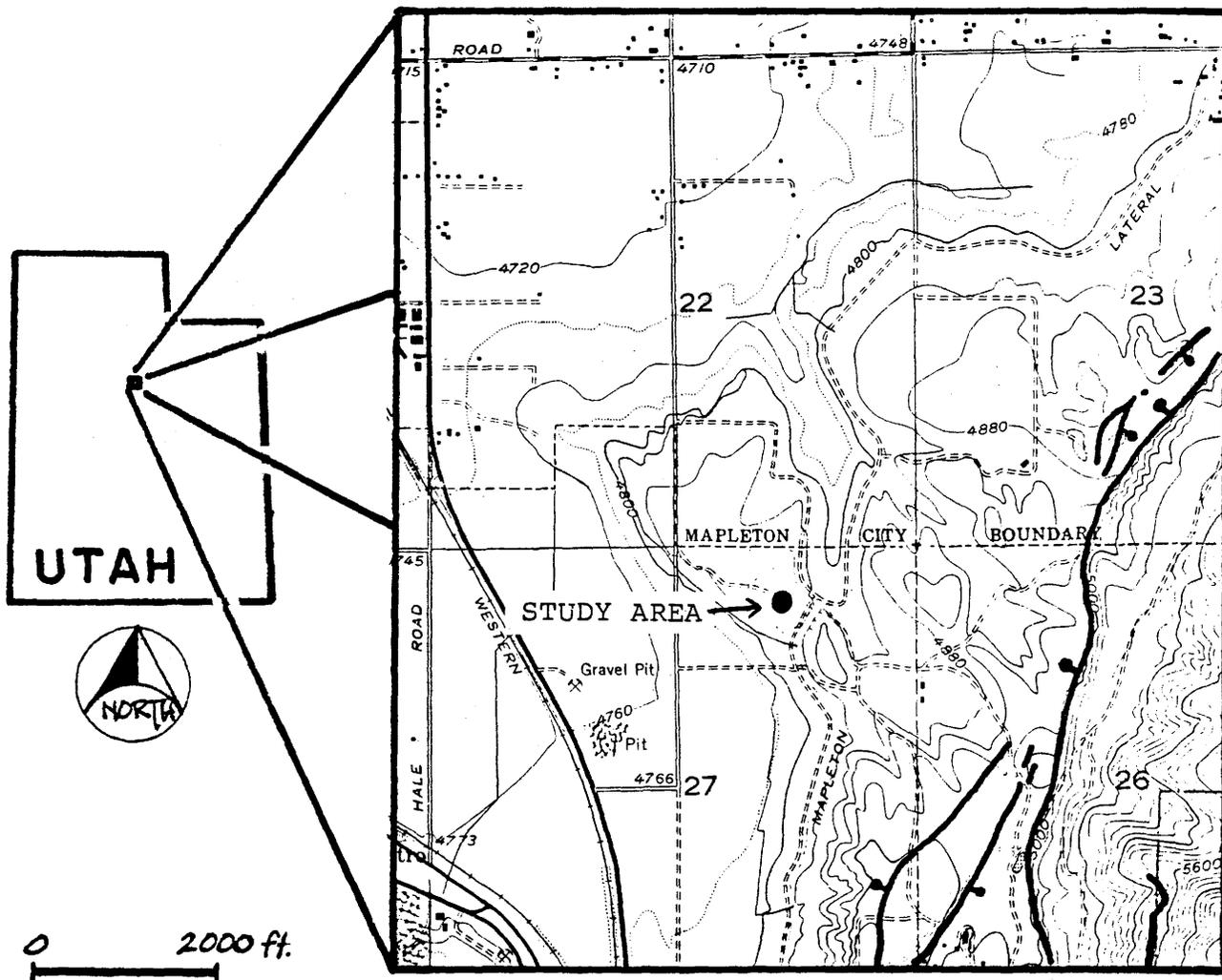


Figure 1. Map showing the location selected by Mapleton City for a water tank. Faults are depicted by heavy lines, with the bar and ball on the downthrown side. Fault mapping adapted from Machette (unpublished data, 1987).

the general shape of a graben (a down-dropped block bounded by faults). No scarps or lineaments were found beyond the edge of the hill where the water tank is to be located, which indicates that the scarps are probably not tectonic in origin. They are most likely the banks of a paleochannel of the Spanish Fork River cut when the base level of the river was regressing to, or halted at, the Lake Bonneville Provo shoreline at about 4800 feet. Seismic tilting may occur at the site (Keaton, 1987). Tilting may be up to several degrees, as is evident at the mouth of Hobbles Creek Canyon.

### Flooding

The area has a very low potential for flooding. The flood insurance rate map (FIRM) (FEMA, 1980) has categorized this area as zone "C", which corresponds to "areas of minimal flooding". The site selected for the tank is well above the surrounding terrain. Any flooding would be due to precipitation which fell at the site.

### Landslides

The sediments at the site selected for the water tank may be prone to landslides, but none have been mapped in the immediate area. The laminated clay in the soil may retain water which could induce slope failure, and care should be taken in the design of site drainage to remove water from the area. The stability of cut slopes during excavation for the buried tank should be addressed by the soil foundation investigation.

### Soil Conditions

The soil at the site has been classified as PaB, Parleys loam, surrounded by WhE, Welby-Hillfield silt loam (Swenson, 1972). The PaB soil is characterized by 0-3° slopes with the water table below 6 feet. Engineering properties which may be of concern are a moderate shrink-swell potential and moderately slow permeability. The WhE soil has 10-30° slopes, moderate bearing strength, low shrink-swell potential, but a high erosion hazard. These soil classifications are only valid for the top approximately 5 feet of material, and engineering properties below this level should be investigated in the soil foundation report.

## CONCLUSIONS AND RECOMMENDATIONS

No conditions exist which would preclude the construction of the water tank at the site. The location is in the Uniform Building Code seismic zone 3, and should be designed to withstand ground accelerations as indicated above depending on the expected life of the structure. Grading should be engineered to divert water away from the tank and not allow ponding, and site drainage should be designed to control erosion. A standard soil foundation investigation should be prepared which includes analyses for potential shrink-swell problems and stability of cut slopes. The excavation should be examined for evidence of any buried faults which may not have surface expression.

## REFERENCES

Davis, F.D., 1983, Geologic map of the southern Wasatch Front, Utah: Utah Geological and Mineral Survey Map 55-A, scale 1:100,000.

- FEMA (Federal Emergency Management Agency), 1980, Flood insurance rate map for the city of Mapleton, Utah, Utah County: Federal Emergency Management Agency, National Flood Insurance Program, community-panel no. 490156 005 B, scale 1:12,000.
- Keaton, J.R., 1987, Potential earthquake-induced tectonic subsidence along the Wasatch Front, north-central Utah, in McCalpin, James, ed., Proceedings of the 23rd Symposium on Engineering Geology and Soils Engineering: Logan, Utah, Utah State University, p. 19-34.
- Swenson, J.L., 1972, Soil survey of Utah County, Utah: United States Department of Agriculture, Soil Conservation Service, in cooperation with Utah Agricultural Experiment Station, 161 p.
- Youngs, R.R., Power, M.S., Schwartz, D.P., and Green, R.K., 1987, Probabilistic analysis of earthquake ground shaking hazard along the Wasatch Front, Utah, in Gori, P.L., and Hays, W.W., eds., Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Open-File Report 87-585, v. 1, p. M-1-M-110.

Project: Evaluation of lineaments at the proposed Provo City landfill, Goshen Valley, Utah		Requesting Agency: Utah County Board of Adj.	
By: Robert M. Robison	Date: April 20, 1987	County: Utah	Job No.: U4
USGS Quadrangle: Goshen Valley North			

## INTRODUCTION

The proposed Provo City landfill is located in Goshen Valley, Utah, in Sec. 17, T. 9 S., R. 1 W., SLB&M (fig. 1). The site is about 2 miles west of the southern end of Utah Lake and approximately 2 miles east of the Tintic Mountains. Elberta City is approximately 5.5 miles to the south.

The purpose of this investigation was to evaluate lineaments in Section 17 to determine if they were formed by surface fault rupture. Several lineaments were identified by the Utah County Geologist (Robison, 1986a) which may have been produced by faulting. The Utah County Board of Adjustments (minutes dated January 13, 1987) authorized an investigation of all lineaments. The Utah County Geologist had the responsibility to locate exploratory trenches and make the interpretation as to the presence/location of any faults found.

The scope of this investigation included a review of pertinent literature and aerial photographs, field reconnaissance, and the excavation, logging, photographing, and interpretation of eight trenches (fig. 2). Trench locations were selected during a field reconnaissance on March 6, 1987, by the Utah County Geologist. Duane Whiting of ESE, Steve Sevier of Elberta Farms, and Dale Stephenson and Carl Carpenter of Provo City, were present when the trenches were sited.

Eight trenches were excavated on March 24, 25, and 26, 1987 (fig. 2) across lineaments L1, L2, and L4. Lineament L3 had no surface expression or traceable linear features, and hence was not trenched. Kimm M. Harty and Suzanne Hecker of the Utah Geological and Mineral Survey logged trench #1 (fig. 2). Robert M. Robison (Utah County Geologist) and John D. Garr (EarthFax Consultants) logged the other trenches. EarthFax Consultants were hired by Environmental Science and Engineering to participate in the investigation.

## TRENCH LOCATIONS AND DESCRIPTIONS

Trenches were numbered from north-to-south on the eastern lineament (L1, trenches numbered 1 to 4, fig 2.) and from south-to-north on the western lineament (L2, trenches numbered 5 to 7, fig. 2). The eighth trench (number 2a, fig 2) was parallel to trench number 2 to verify continuity of the sediments through a disturbed area. Horizontal level lines were used for elevation control and reference to bedding and features in logging trenches. The original scale of the trench logs was 1:50.

Five units were recognized in trench number 1 and were correlated in all of the trenches. A detailed explanation of each unit giving the type of deposit, thickness, color, texture and features, and genesis, is included in the appendix. A summary of

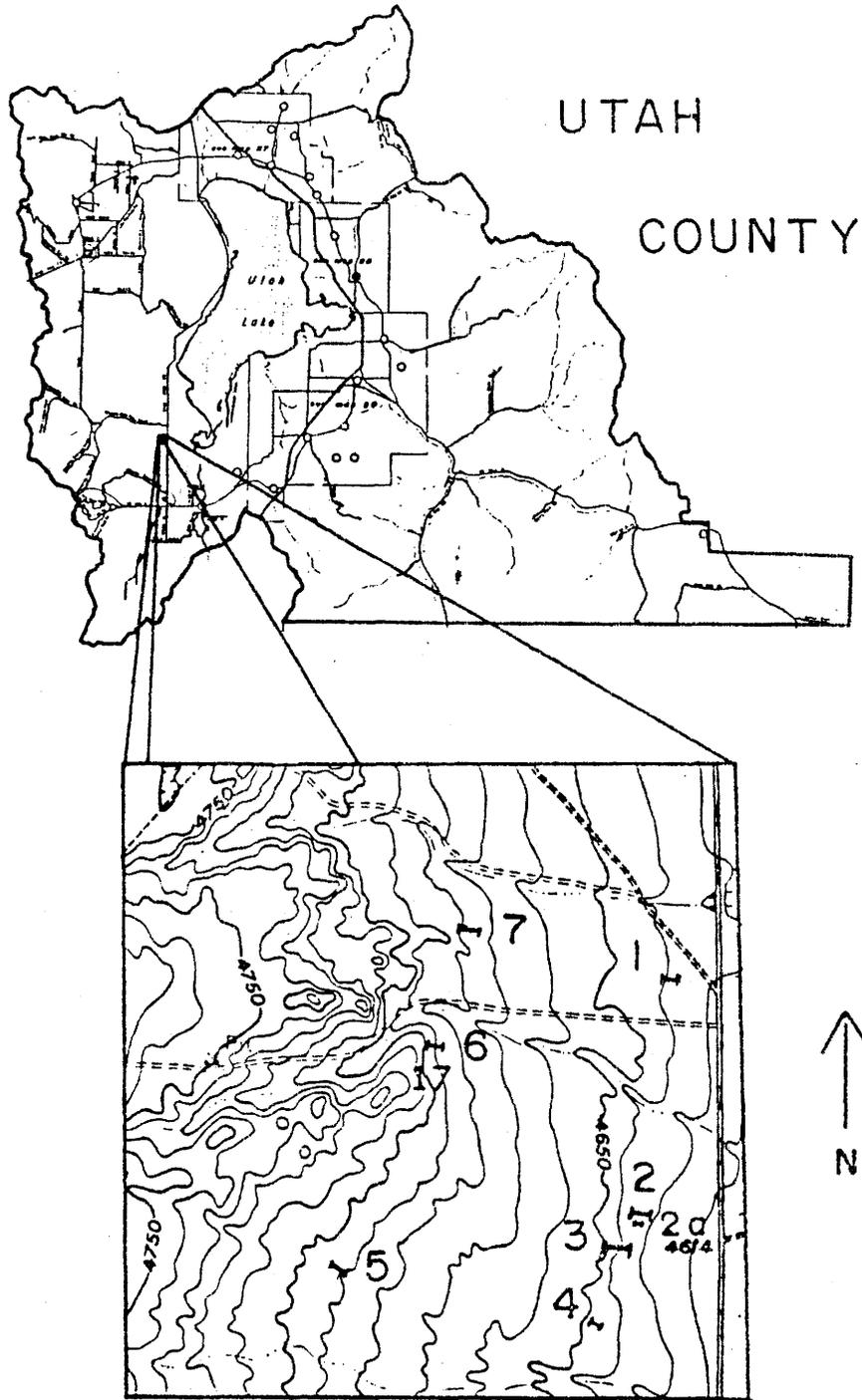


Figure 1. Map showing the location of the study area, Section 17, T. 9 S., R. 1 W., SLB&M, Goshen Valley, Utah. Single digit numbers refer to trenches. See text for logs and descriptions of trenches.

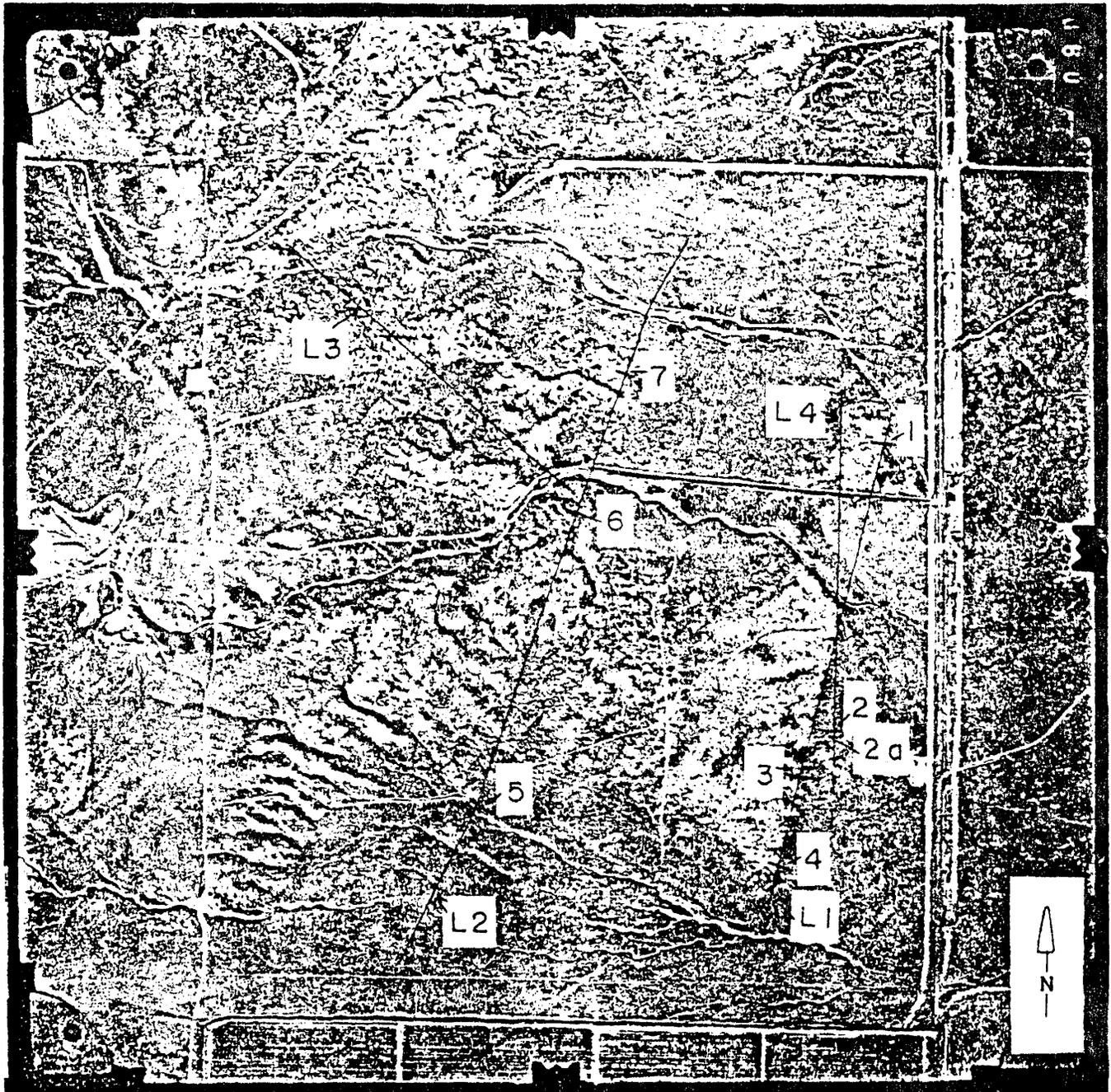


Figure 2. December, 1986, aerial photograph of the study area. Lineaments are labeled L1 to L4. Trench locations are labeled 1 to 7. Scale is approximately 1:11,500.

the location and principal features in each trench is given below:

Trench Number 1. This trench was across the north end of lineament L1 (fig. 2, Appendix A). Five stratigraphic units were delineated in this trench. The continuity of the beds can be seen in trench log #1 (Appendix A). Stringers of sand can be traced through the deposits. The fractures in the clayey sediments may be the result of shrinking from desiccation, or from liquefaction.

Trench Number 2. This trench along lineament L4 (fig. 2). A total of 4 sedimentary units were logged in the trench. a large burrow(?) in the central portion of the trench made linear continuity of deposits unclear. A second trench (2a, fig. 2) was excavated parallel to trench 2 which had continuous bedding in the region of the burrow. No logs were made of trench 2a, but photos (not included in this report) were taken.

Trench Number 3. A 5+ m high scarp was present at the site of trench number 3. A 36 m long trench was excavated across this scarp to ensure that any faults would be discovered (trench #3, Appendix A). Five continuous stratigraphic units were logged in this trench.

Trench Number 4. This trench was located at the south end of lineament L1 (fig. 2). Three continuous stratigraphic units were found.

Trench Number 5. Trench 5 was located at the south end of lineament L2 (fig. 2). Three sedimentary units were identified. Unit 1 was subdivided into units 1 and 1a because of the presence of lacustrine(?) gastropods in unit 1a (Appendix A). Sand filled fissures were common.

Trench Number 6. Trench number 6 was located in the central portion of lineament L2 (fig. 2). Three sedimentary units were found (Appendix A). Fissures were common and most were filled with sand. Several small (< 2 cm) fissures were open within unit 3.

Trench Number 7. Trench 7 (fig. 2) was located on the north end of lineament L2. A 3 m (9 foot) scarp was trenched approximately 11 feet deep, which revealed only eolian sand. The scarp was apparently a dune slip face (lee slope). The trench walls were very unstable and no logs were made of the trench. Photographs were taken of the trench but were not included in this report.

## DISCUSSION

Sediments and features of Pleistocene Lake Bonneville dominate the study area. The western margin of the site is approximately at the Provo shoreline of the lake occupied 14,000-15,000 years ago. Shoreline deposits are chiefly gravel which grades eastward to offshore facies of sand, silt, and clay. Most of the lake sediments are beneath this covering of sandy Holocene alluvium and eolian material. In addition to these surficial deposits, trenches exposed sand and gravel. Deposits representing the transgression of Lake Bonneville about 25 thousand years ago (unit 5, Appendix); deep lake clays of the highstand about 15 to 16 thousand years ago (units 3 and 4) and the drop to the Provo Shoreline 15 thousand years ago, and the regression of the lake out of the study area about 13 to 14 thousand years ago (unit 1a and 2). For a

more complete discussion of the history of Lake Bonneville see Currey and Oviatt (1985).

The lineaments identified for study varied in surficial expression and probable origin. The aerial photographs used by Robison (1986) to identify lineaments were taken in 1959, and the photos used by ESE were 1986 photos. Lineament number 1 (fig. 2) was less visible on the 1986 photo as compared to the 1959 photo, and was at a slightly different orientation. Lineament number 2 (fig. 2) was more evident on the 1986 photos. In addition to surface faulting, possible origins of the lineaments include grazing patterns, animal trails, fence lines, abandoned canals or ditches, differential erosion of surficial material, or natural drainage lines. The change in the character of the lineaments in the 27 years between the photos may be the result of stabilization after previous land uses or continued erosion of natural features. Also, several sand dunes are present roughly parallel to the lineaments.

No existing geologic or surficial maps indicate surface fault ruptures in this area, and none were found in the investigation. Faulting at depth has been inferred by Cordova (1970), but no faults were extended to the ground surface. Several trenches exhibited layers of sediments with sand-filled fissures with little or no offset. These fissures trended roughly parallel to lineaments, but none were found which reached the ground surface and are not the cause of the lineaments. The sand-filled fractures may be the result of either liquefaction or desiccation. If they resulted from earthquake-induced liquefaction, the earthquake causing the liquefaction would not necessarily have had an epicenter at the location of the liquefaction. A large earthquake on the Wasatch Fault, about 12 miles east, would shake the study area sufficiently hard to induce liquefaction when ground-water conditions were favorable. The earthquake would have had to occur after deposition of the clayey sediments (units 3, Appendix A) about 13,000 to 12,000 years ago, but before the water table had dropped, possibly about 10,000 years ago.

If the sand-filled features are the result of desiccation, then a triggering earthquake is not necessary. The fissures could have formed any time following the retreat of Lake Bonneville from this level about 12 ka. Surface water or wind could have carried the sand into the fissures. Locally, some of the fissures were open (+/- 1 cm) within unit 3.

#### CONCLUSIONS AND RECOMMENDATIONS

The trenches revealed no features which could be interpreted as tectonic faults. The trenches were sufficiently deep to encounter well-bedded late Pleistocene (Lake Bonneville age) and Holocene sediments in which offsets due to faulting would have been readily apparent. The lineaments must be the result of past land uses, meandering drainages, and/or wind erosion and deposition.

Small sand filled fractures in trenches may be result of liquefaction during times of higher ground-water or from desiccation as sediments dried. Under present conditions, the liquefaction potential for this area is very low (Anderson and others, 1986). There appears to be no surface fault rupture hazard at the site, however, trenches or other excavations produced from the construction of the landfill should be periodically inspected by the Utah County Geologist to check for possible faults in areas not covered by this investigation.

#### SELECTED REFERENCES

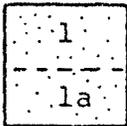
- Anderson, L.R., Keaton, J.R., and Bischoff, J.E., 1986, Liquefaction potential map for Utah County, Utah: Utah State University and Dames & Moore, unpublished report for U.S. Geological Survey 46 p.
- Cordova, R.M., 1970, Ground water conditions in Southern Utah Valley and Goshen Valley, Utah: Utah Department of Natural Resources Technical Publication No. 28, 79 p.
- Currey, D.R., and Oviatt, C.G., 1985, Durations, average rates, and probable causes of Lake Bonneville expansions, still stands, and contractions during the last deep-lake cycle, 32,000 to 10,000 years ago: in Kay, P.A., and Diaz, H.F., eds., Problems of and prospects for predicting Great Salt Lake levels, Conference Proceedings, Center for Public Affairs and Administration, University of Utah, p. 9-24.
- Robison, R.M., 1986a, Elberta landfill site; unpublished Utah County Planning Commission Letter, 2 p.
- , 1986b, Elberta landfill site (Provo, Utah): unpublished Utah County Planning Commission Letter, Dec. 1986, 4 p.
- Whiting, Duane, 1986, Evaluation of hydrologic and seismic conditions, proposed sanitary landfill site in Goshen Valley, Utah: unpublished report by Environmental Science and Engineering to Elberta Farms, Inc., Elberta, Utah, 55 p.

APPENDIX

EXPLANATION FOR TRENCH LOGS

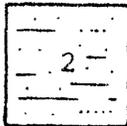
UNIT

DESCRIPTION



Sand, silt (SP, SM, ML): some organic material, gravel present locally; unit may be >1 m thick; light brown to tan, Munsell color is 2.5Y 7/2 (dry) to 2.5Y 6/4 (damp); if sand is predominant, color may be 10YR 5/3. Material is eolian sand, loess and/or alluvium, roots are present and burrows are abundant. This unit is the present ground surface and is probably still being deposited.

Unit 1a has sand with features and color similar to unit 1. This unit is bedded with pockets of gastropods, indicating that it may be lacustrine in origin and older than unit 1, possibly 13,000 to 14,000 years ago.



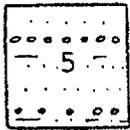
Interbedded clay, silty clay and clayey silt, fine sand, (CL, CL-ML, SM): clay content increases toward bottom of unit, sand increases toward top of unit; unit thickness may be 2.6 m; color is green to gray, lower unit is 5Y 5.5 to 6.1 with laminations of 2.5Y 8/2, unit grades upward to 5Y 7/2; laminated, may have sand filled fractures locally; probably represents the regressive deposits of Lake Bonneville, about 15,000 - 14,000 years ago.



Blocky clay (CH): homogeneous, maximum thickness about 1 m; brown to reddish brown 10YR 5/2-3; some laminations or mottling present; may locally have sand filled fissures. CaCO<sub>3</sub> horizon may be present at the top of unit; these deposits may represent the deep water cycle of Lake Bonneville, about 18,000 years ago.

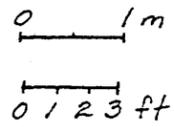
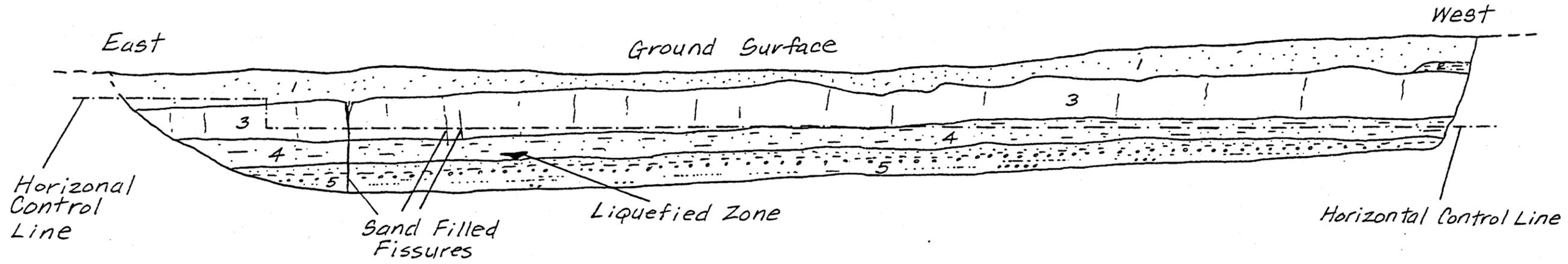


Interbedded clay, silty clay and clayey silt, some fine sand (CL, CL-ML, SM): clay content decreases at the base of unit; resembles unit 2; thickness is about .9 m maximum; laminated, color is green to gray, 5Y 6/1 with streaks of 5Y 8/1 to 7/2; some sand filled fissures present; this unit was probably deposited in the deepening waters of the transgression of Lake Bonneville, about 19,000 to 20,000 years ago.

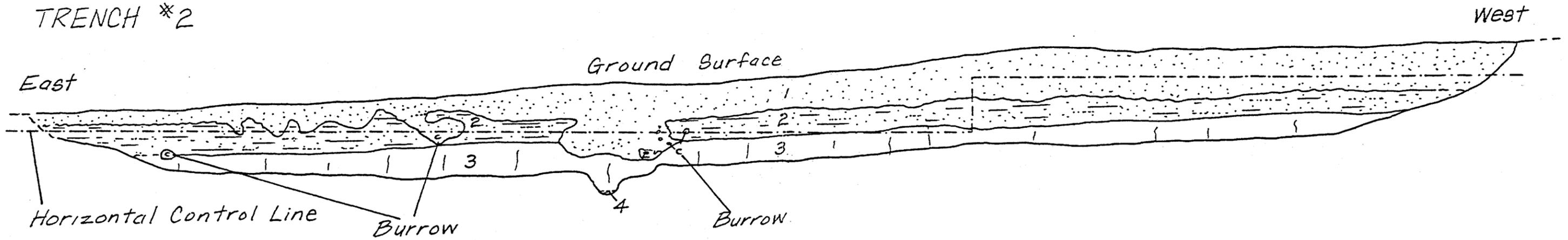


Interbedded gravel, sand, (GM, SM): bedded gravel, moderately to well sorted in places, maximum clast size 10 cm; unit thickness exceeds 1.2 m; light brown, 10YR 5/4, a layer of red sand (oxidized iron stain) may be present at the contact between unit 4; liquefaction features (small diapirs) may be present at the upper contact; this unit may represent the transgressive gravels of Lake Bonneville, about 20,000 years ago.

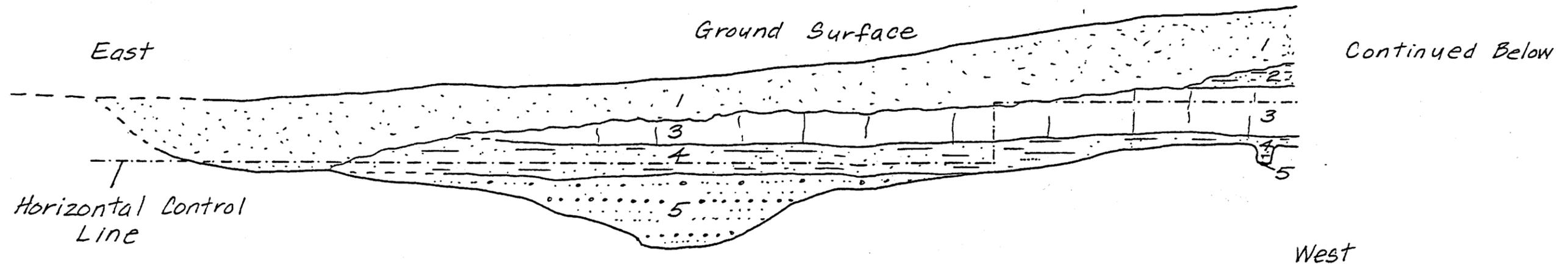
TRENCH #1



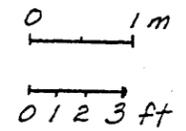
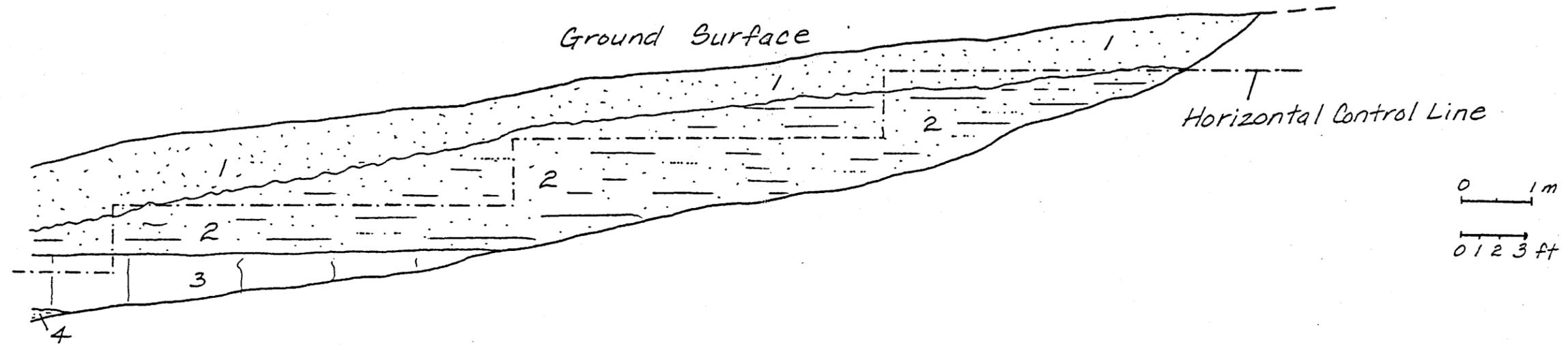
TRENCH #2



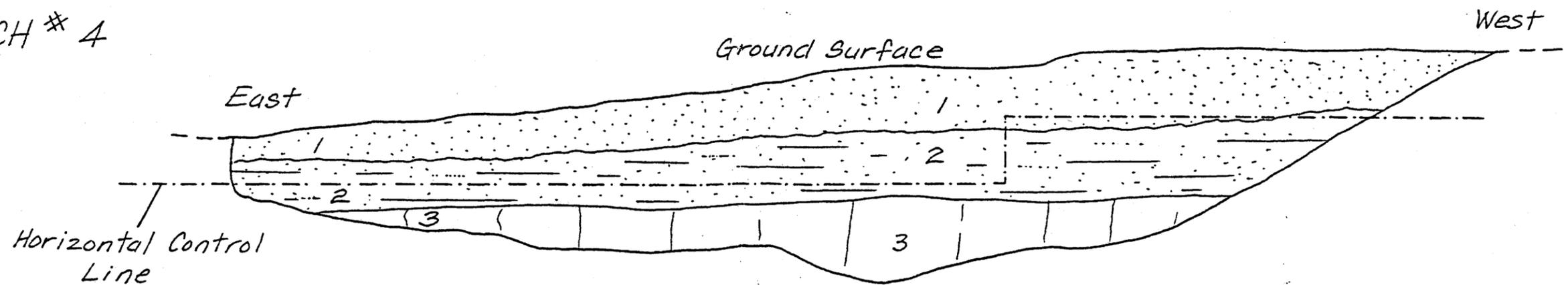
TRENCH # 3



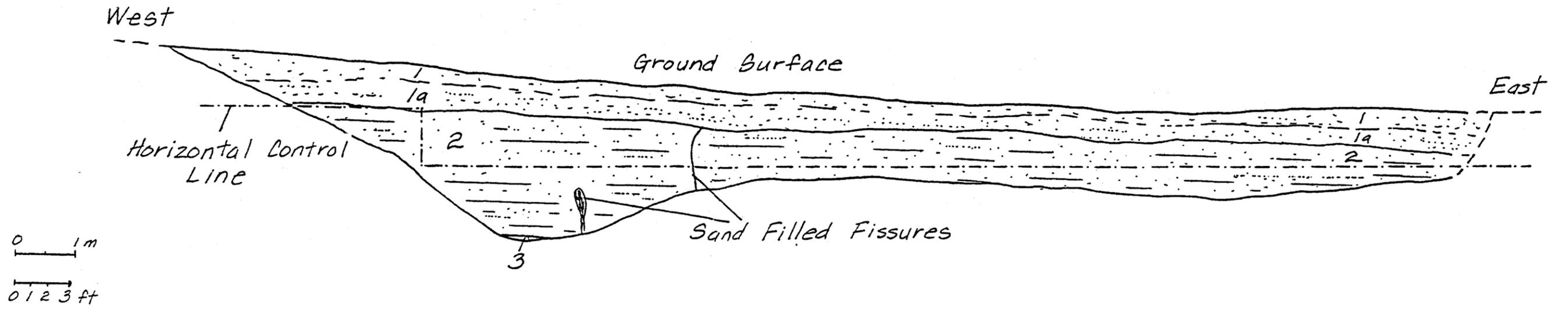
Continued from Above



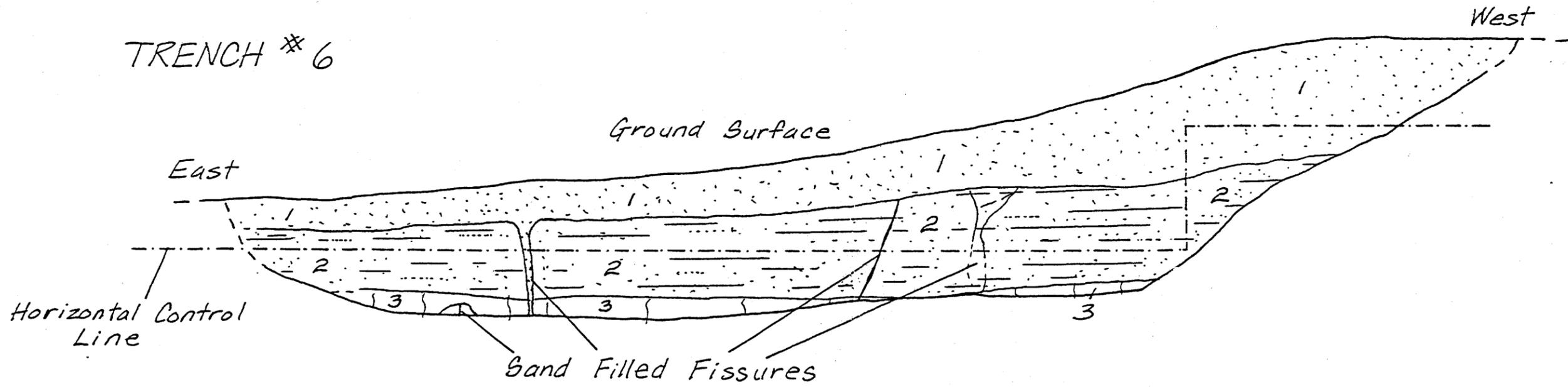
TRENCH # 4



TRENCH # 5



TRENCH # 6



ERRATA FOR TECHNICAL REPORTS OF THE  
WASATCH FRONT COUNTY GEOLOGISTS  
JUNE 1985 TO JUNE 1988

Utah Geological and Mineral Survey

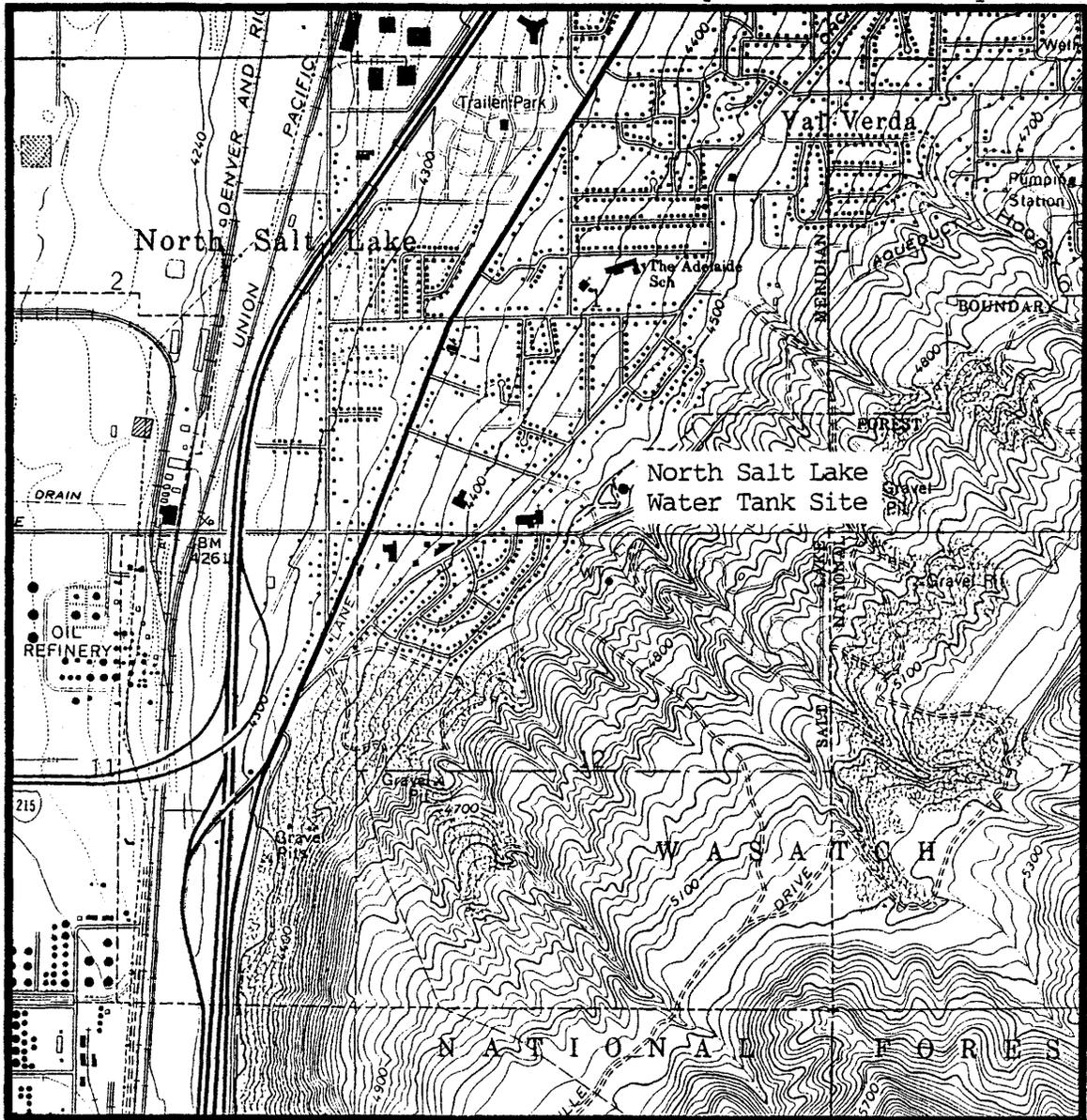
Report of Investigation 218

December 1988

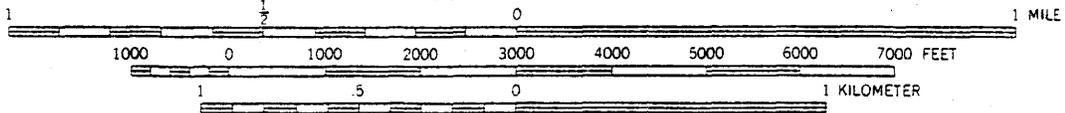
Due to an oversight, the following figures were inadvertently omitted from the original report:

- D-1 Attachment 1. Landslide classification and terminology.
- D-2 Attachment 1. Location map.  
Attachment 2. Test pit location map.  
Attachment 3. Test pit logs.  
Attachment 4. Map showing traces of surface fault rupture,  
Wasatch fault zone.
- D-3 Attachment 1. Landslide classification and terminology.
- D-4 Attachment 1. Landslide classification and terminology.
- SL-2 Figure 1. Test trench locations, and fault exposures.  
Figure 2. Generalized trench diagrams, proposed Dresden  
Place Apartment Complex.
- U-2 Figure 1. Map showing location of study area.



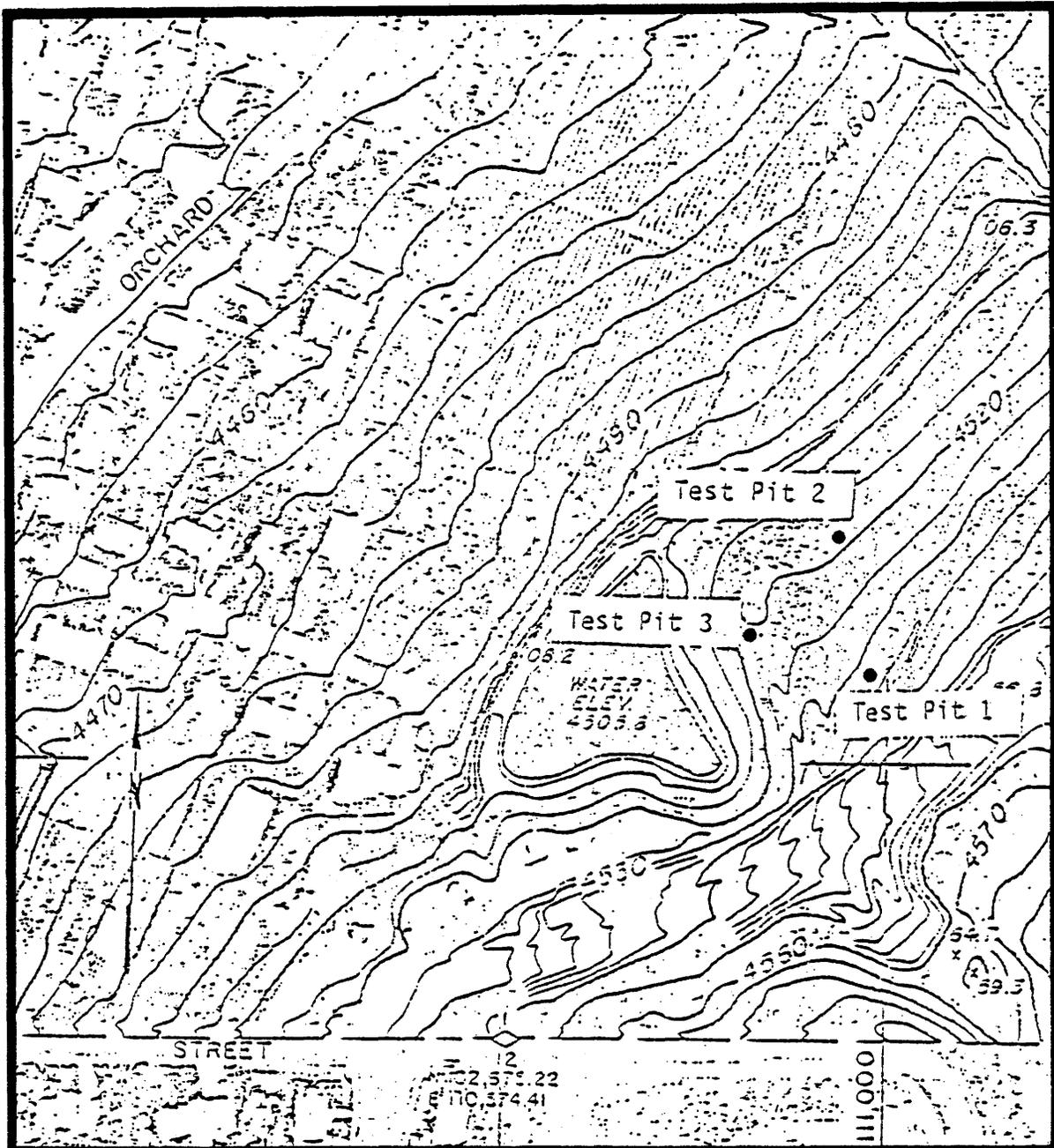


SCALE 1:24 000



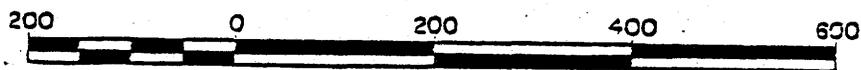
CONTOUR INTERVAL 20 FEET  
 DOTTED LINES REPRESENT 5-FOOT CONTOURS  
 NATIONAL GEODETIC VERTICAL DATUM OF 1929

Location Map



CONTOUR INTERVAL: 2' & 5'

PHOTOGRAPHY DATE: APRIL 1982



SCALE: 1" = 200'

Test pit location map

## Attachment 3

## Test Pit Logs

Test Pit 1

- 0" - 46" Silty sand (SM); black, low density, nonplastic moist.
- 46" - 106" Well-graded sand (SW); light brown, low density, nonplastic, moist.

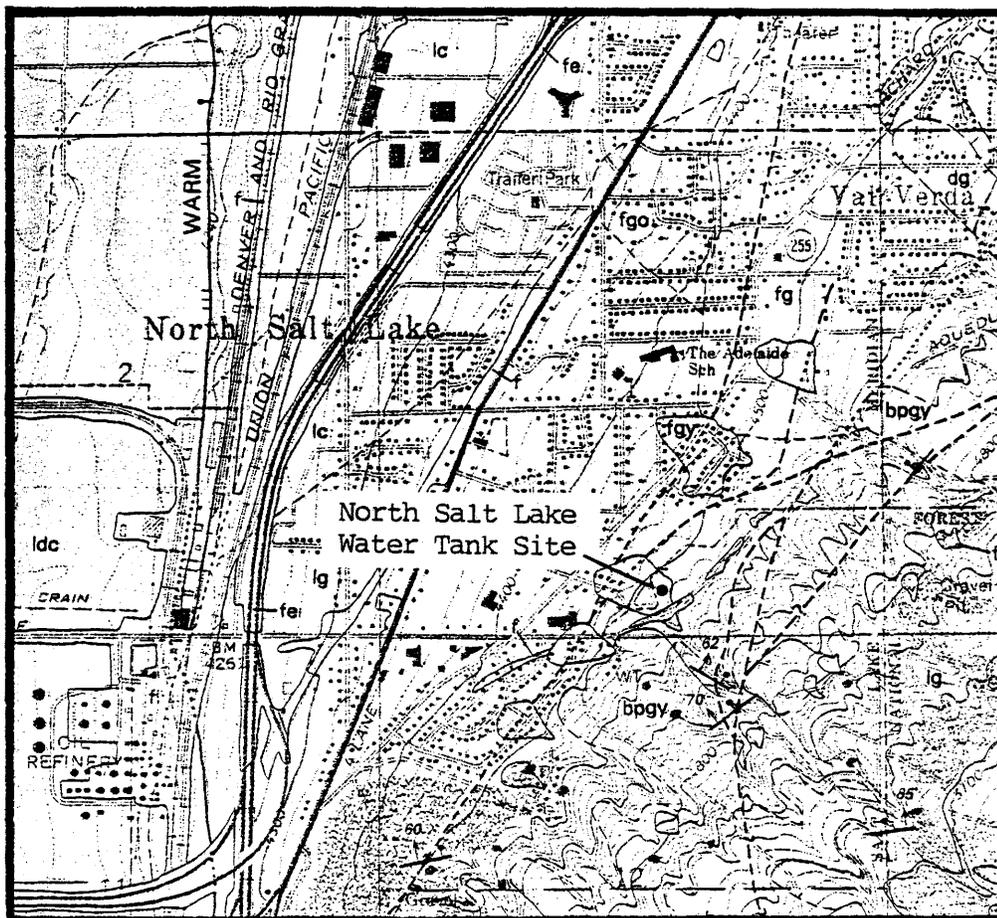
Test Pit 2

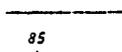
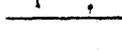
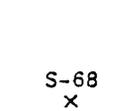
- 0" - 51" Silty sand (SM); dark brown, low density, nonplastic, moist.
- 51" - 97" Well-graded sand (SW); light brown, low density, nonplastic, moist; crudely bedded.
- 97" -120" Well-graded sand (SW); brown, low density, nonplastic, moist.

Test Pit 3

- 0" - 53" Silty sand (SM); dark to light brown, low density, nonplastic, moist; some poorly graded beds.
- 53" - 105" Silty sand (SM); black, low density, nonplastic, moist.

Attachment 4

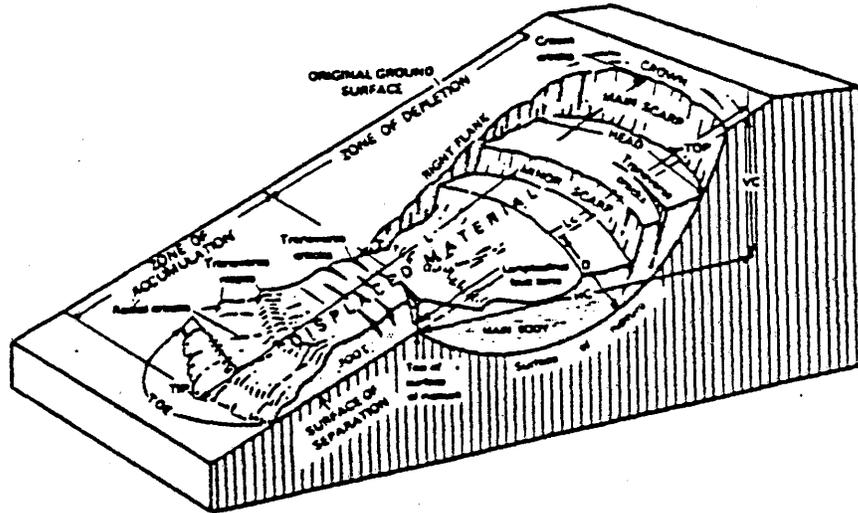


- 
 CONTACT—Long-dashed where approximately located; short-dashed where inferred; domed where concealed
- 
 FAULT, SHOWING DIP—Long-dashed where approximately located; short-dashed where inferred; domed where concealed; queried where doubtful. Bar and ball on downthrown side. Shown only where surficial deposits appear to have been involved in the faulting
- 
 LAKE BONNEVILLE SHORELINE SCARP—Hachures point down-slope
- 
 1873 SHORELINE OF GREAT SALT LAKE—Dotted where concealed
- 
 S-68  
X LOCALITY MENTIONED IN TEXT

Map showing traces of surface fault rupture, Wasatch fault zone (from Van Horn, 1982). Scale 1:24,000. See Van Horn (1982) for explanation of surficial geologic units.

TYPE OF MOVEMENT			TYPE OF MATERIAL		
			BEDROCK	ENGINEERING SOILS	
				Predominantly coarse	Predominantly fine
FALLS			Rock fall	Debris fall	Earth fall
TOPPLES			Rock topple	Debris topple	Earth topple
SLIDES	ROTATIONAL	FEW UNITS	Rock slump	Debris slump	Earth slump
		MANY UNITS	Rock block slide	Debris block slide	Earth block slide
	TRANSLATIONAL	FEW UNITS	Rock slide	Debris slide	Earth slide
		MANY UNITS			
LATERAL SPREADS			Rock spread	Debris spread	Earth spread
FLOWS			Rock flow (deep creep)	Debris flow (soil creep)	Earth flow
COMPLEX			Combination of two or more principal types of movement		

Landslide classification and terminology

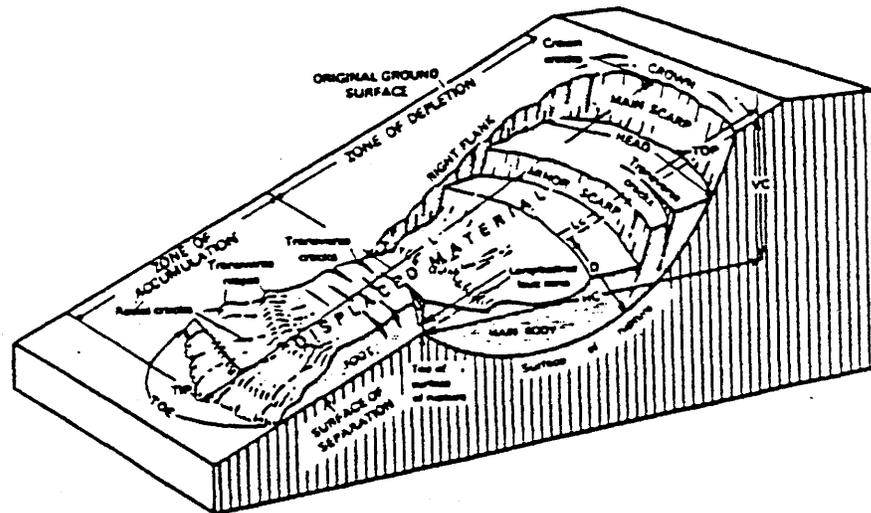


Source:

Varnes, D. J., 1978, Slope movements types and processes, in Schuster, R. L., and Krizek, R. J., eds., Landslides, Analysis and Control: National Academy of Sciences, Transportation Research Board Special Report 176, p. 11 - 33.

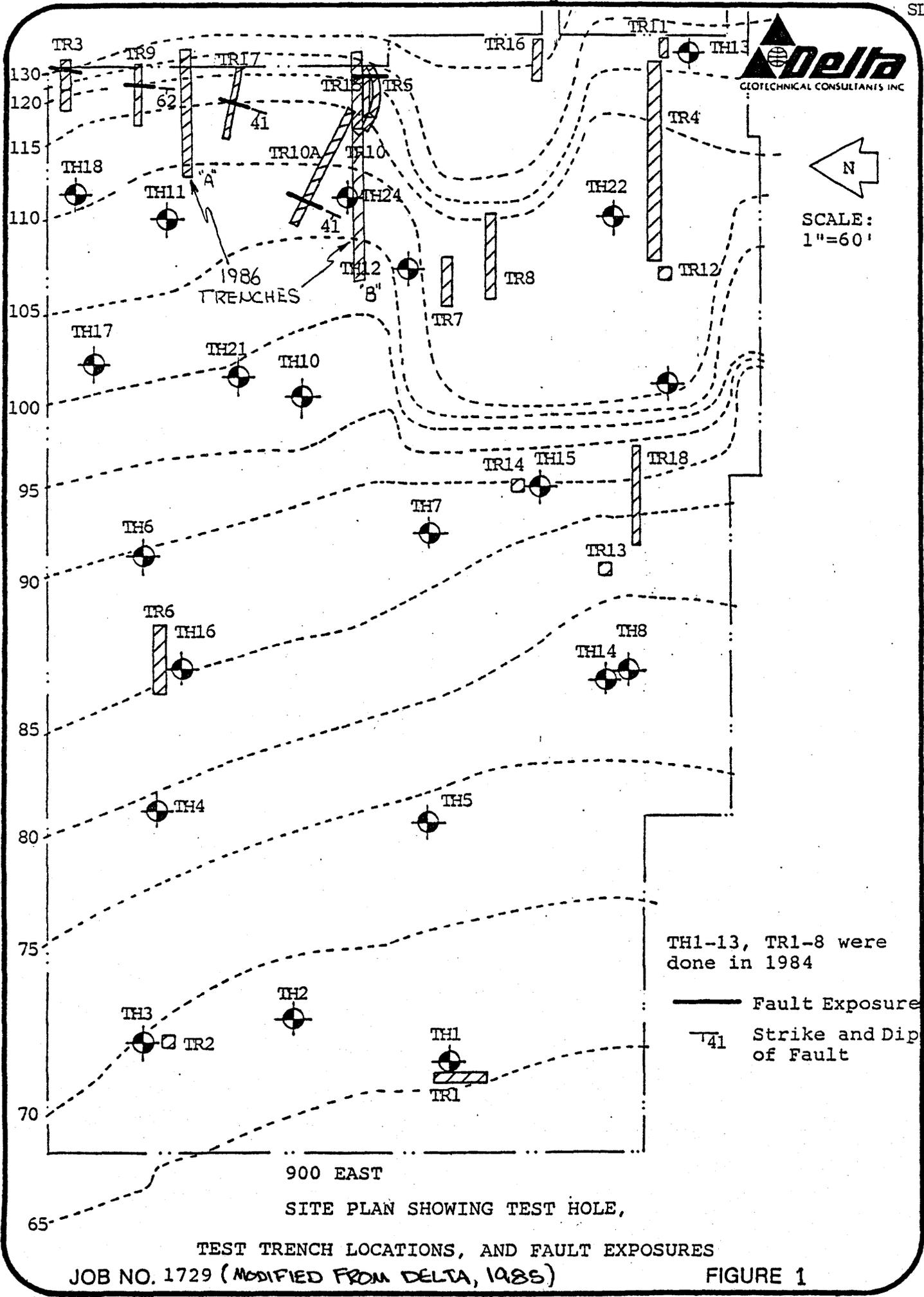
TYPE OF MOVEMENT			TYPE OF MATERIAL		
			BEDROCK	ENGINEERING SOILS	
				Predominantly coarse	Predominantly fine
FALLS			Rock fall	Debris fall	Earth fall
TOPPLES			Rock topple	Debris topple	Earth topple
SLIDES	ROTATIONAL	Few UNITS	Rock slump	Debris slump	Earth slump
	TRANSLATIONAL		Rock block slide	Debris block slide	Earth block slide
		MANY UNITS	Rock slide	Debris slide	Earth slide
LATERAL SPREADS			Rock spread	Debris spread	Earth spread
FLOWS			Rock flow (deep creep)	Debris flow (soil creep)	Earth flow
COMPLEX			Combination of two or more principal types of movement		

Landslide classification  
and terminology

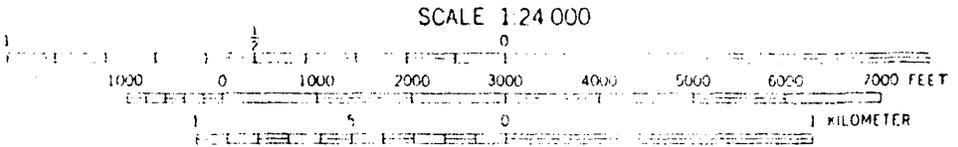
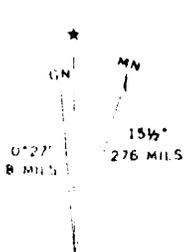
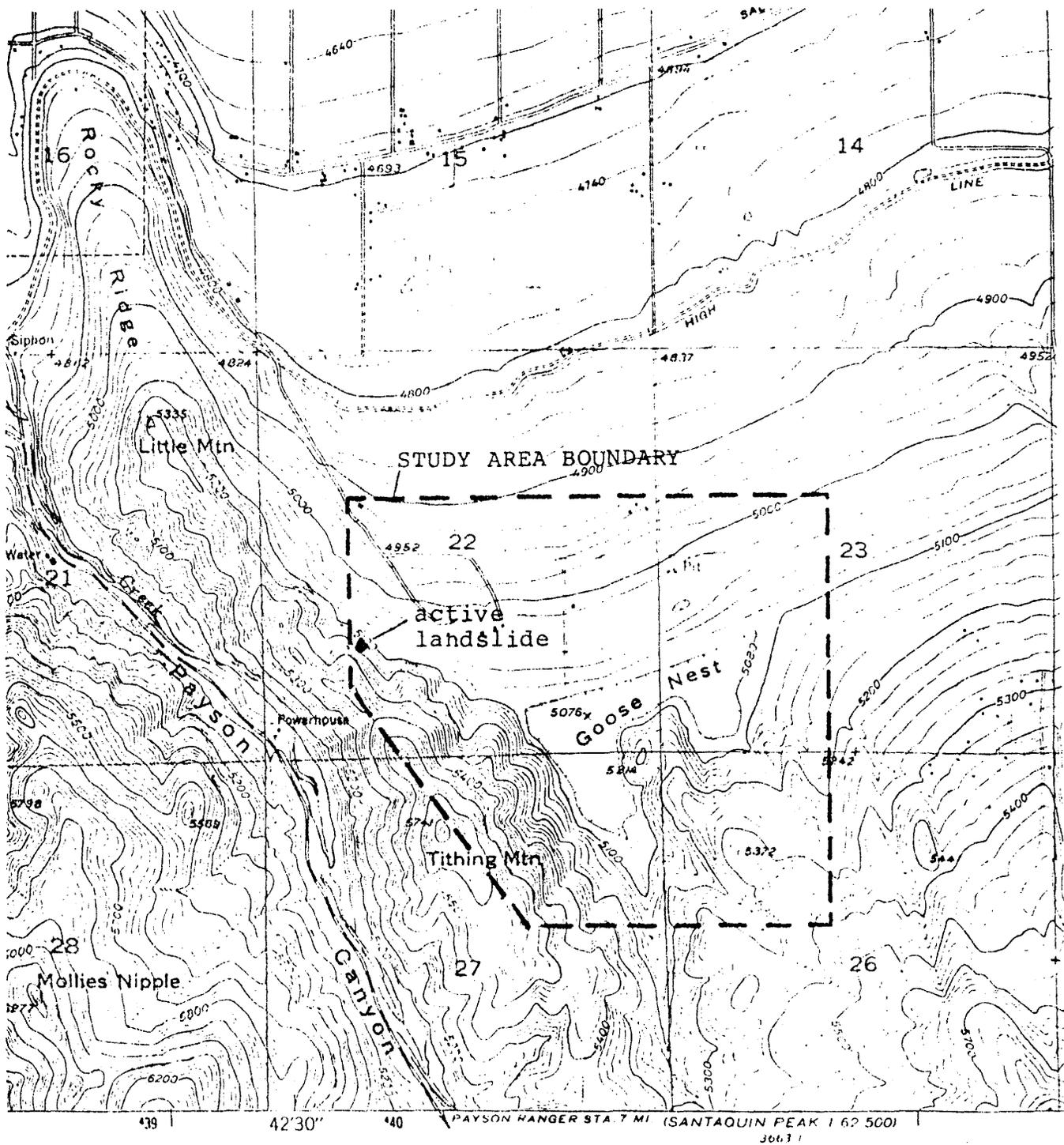


Source:

Varnes, D. J., 1978, Slope movements types and processes, in Schuster, R. L., and Krizek, R. J., eds., Landslides, Analysis and Control: National Academy of Sciences, Transportation Research Board Special Report 176, p. 11 - 33.



SITE PLAN SHOWING TEST HOLE,  
TEST TRENCH LOCATIONS, AND FAULT EXPOSURES  
JOB NO. 1729 (MODIFIED FROM DELTA, 1985) FIGURE 1



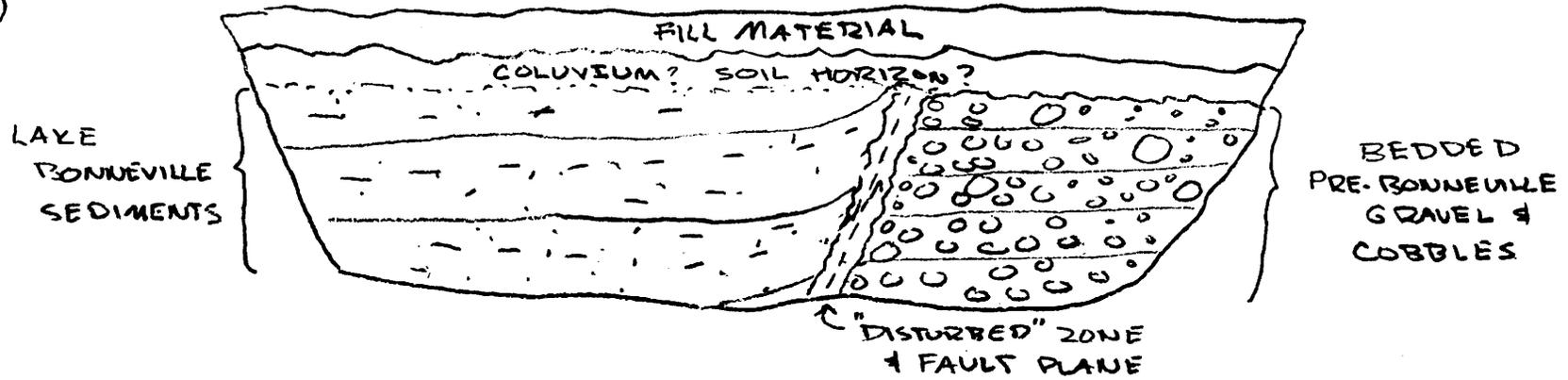
CONTOUR INTERVAL 20 FEET  
DOTTED LINES REPRESENT 10 FOOT CONTOURS  
NATIONAL GEODETIC VERTICAL DATUM OF 1929

UTM GRID AND 1975 MAGNETIC NORTH  
DECLINATION AT CENTER OF SHEET

Figure 1. Map showing location of study area.

FIGURE 2:  
 GENERALIZED TRENCH DIAGRAMS  
 PROPOSED DRESDEN PLACE APARTMENT COMPLEX  
 NOT TO SCALE!

(A)



(B)

